CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE
CALIFORNIA

Public Draft

2012 Central Valley Flood Protection Plan

Attachment 8G: Life Risk Analysis

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section states the purpose of this attachment, gives background information (including a description of planning areas, goals, and approaches), provides an overview of flood risk and the use of life risk as an indicator of flood risk, and provides an overview of the report organization.

1.1 Purpose of this Attachment

The 2012 Central Valley Flood Protection Plan (CVFPP) measures flood risk for the No Project condition and various 2012 CVFPP approaches so that quantitative comparisons can be made among the different flood risk management approaches, summarized below (Section 2 of the 2012 CVFPP describes the approaches in more detail). Economic analysis for the 2012 CVFPP is described in the Attachment 8F: Flood Damage Analysis. This attachment describes the 2012 CVFPP Life Risk Calculation (LRC) method and results.

1.2 Background

As authorized by Senate Bill 5, also known as the Central Valley Flood Protection Act of 2008, the California Department of Water Resources (DWR) has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the State Plan of Flood Control (SPFC), and will be updated every 5 years.

As part of development of the CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Sacramento-San Joaquin Delta (Delta).

1.3 CVFPP Planning Areas

For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

- **SPFC Planning Area –** This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010a)). The State of California's (State) flood management responsibility is limited to this area.

- **Systemwide Planning Area –** This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

The life risk analysis described in this attachment was conducted entirely within the SPFC Planning Area.

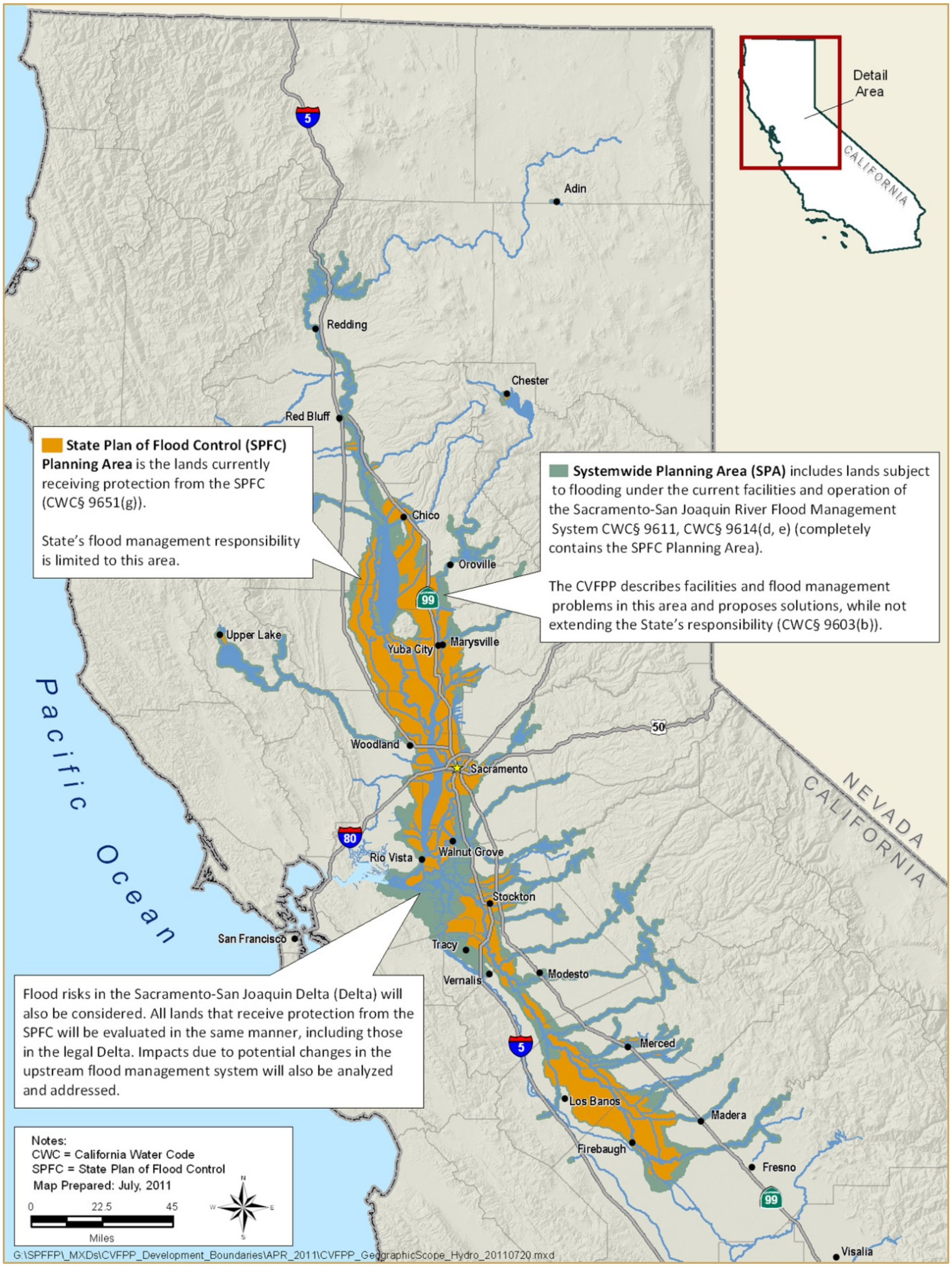


Figure 1-1. Central Valley Flood Protection Plan Planning Areas

1.4 2012 CVFPP Planning Goals

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal** – Improve Flood Risk Management
- **Supporting Goals**:
  - Improve Operations and Maintenance
  - Promote Ecosystem Functions
  - Improve Institutional Support
  - Promote Multi-Benefit Projects

The life risk analysis is directly related to the primary goal because improving flood risk management will reduce life risk in areas protected by levees.

1.5 2012 CVFPP Planning Approaches

In addition to **No Project**, three fundamentally different preliminary approaches to flood management were initially compared to explore potential improvements in the Central Valley. These approaches are not alternatives; rather, they bracket a range of potential actions and help explore trade-offs in costs, benefits, and other factors important in decision making. The preliminary approaches are as follows:

- **Achieve SPFC Design Flow Capacity** – Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.

- **Protect High Risk Communities** – Focus on protecting life safety for populations at highest risk, including urban areas and small communities.

- **Enhance Flood System Capacity** – Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these preliminary approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

The life risk analysis reported herein includes results for the following:

- No Project condition
- Achieve SPFC Design Flow Capacity Approach
- Protect High Risk Communities Approach
- Enhanced Flood System Capacity Approach
- State Systemwide Investment Approach

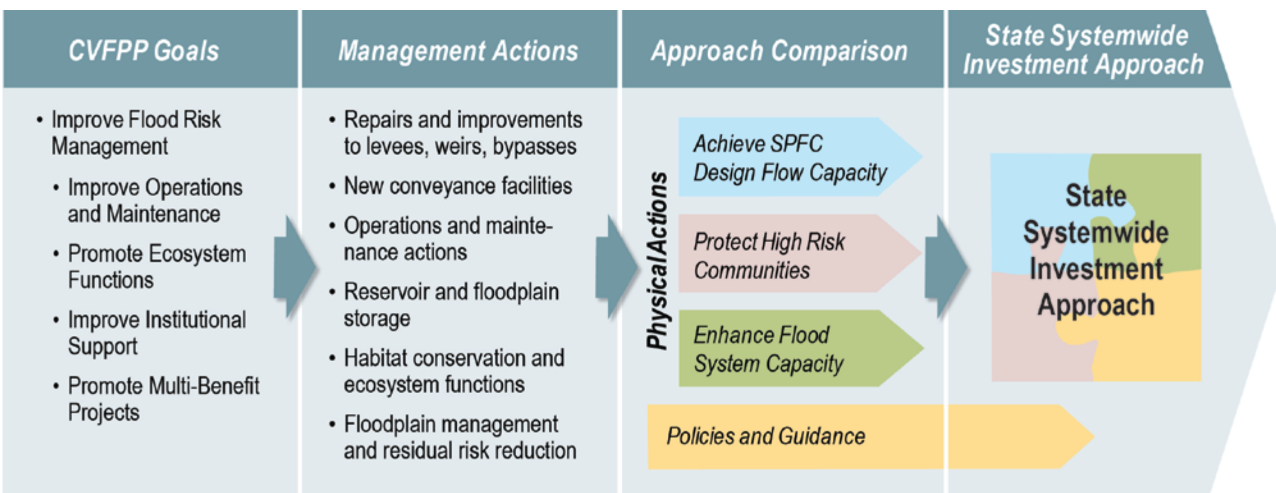


Figure 1-2. Formulation Process for State Systemwide Investment Approach

1.6 Flood Risk Concepts

Since 1986, flood disasters in California have claimed 137 lives, as shown in Table 1-1 (DWR, 2009). Lives were lost during extreme and not-as-extreme events because of system capacity exceedence and other reasons. A goal of the CVFPP is to reduce this life risk.

1.7 Definition of Flood Risk

Flood risk is the likelihood of undesirable consequences due to flood inundation within an identified area given a specified climate condition, land use condition, and flood management system (existing or planned) in place. For convenience, risk often is expressed as the average annual consequence. Flood risk is a function of (1) loading, which is the frequency and magnitude of flood flows, (2) performance of flood risk reduction measures, (3) exposure and vulnerability of people and property in the floodplain, and (4) consequence of inundation.

Flood management actions may reduce risk by changing one or more of the factors listed above. The 2012 CVFPP approaches analyzed in this study aim to reduce flood risk through changes in loading (increased storage and bypass conveyance), performance (levee improvements), and/or consequence (floodplain management actions).

1.8 Life Risk as Indicator of Flood Risk

The consequence of flood inundation may be measured in terms of direct and/or indirect economic cost, loss of life, environmental impact, or other specified measure of flood effect. In the analysis described herein, the consequence of flood risk is represented in terms of potential loss of life.

Life risk, as described herein, is the long-term average annual number of lives potentially lost in an identified area, considering a given climate and land use condition, with a specified plan of flood protection in place.

Table 1-1. California Flood Disasters Since 1986

Date	Disaster Number	Scope (number of counties)	Number of Deaths	FEMA Damage Costs ($ millions)[1]	California Emergency Management Agency Damage Costs ($ millions)[2]	Combined Damage Costs ($ millions)[3]
Feb 1986	758-DR-CA		13	Not reported	$407.50	$715.80
Jan 1988	FP 87-06		Not reported	Not reported	$49.40	$82.20
Feb 1992	935-DR-CA	6	5	$123.20	$53.90	$178.40
Jan 1993	979-DR-CA	25	20	$600	$226	$848.90
Jan 1995	1044-DR-CA	45	11	$741.40	$221.90	$1,005.20
Feb 1995	1046-DR-CA	57	17	$1,100	$132	$1,491.40
Jan 1997	1155-DR-CA	48	8[4]	$1,800	$194.40	$2,350
Feb 1998	1203-DR-CA	40	17	$550	$385.10	$710.30
Jun 2003	1498-DR-CA[5]	2	16	—	—	—
Jun 2004	1529-DR-CA	1	0	$57	$27.20	$65.40
Feb 2005	1577-DR-CA	8	24	$573.10	$291.40	$636.30
Apr 2005	1585-DR-CA	7	0	$198.70	$76.10	$220.60
Feb 2006	1628-DR-CA	40	5	$327.80	$129	$352.10
Jun 2006	1646-DR-CA	16	1	$129.50	$28.90	$139.10
Total	—	—	137	$6,200	$2,220	$11,000

Sources:
Office of Emergency Services (OES), Origins and Development—A Chronology 1917-1999 and OES After Action Reports
FEMA: California Disaster History (http://www.fema.gov/news/disasters_state.fema)
State of California Multi-Hazard Mitigation Plan, October 2007.

Notes:

[1] Costs not adjusted for inflation to 2009 dollars and only report amount FEMA pays out within a defined time frame (e.g., 24 months) after declaration is made.

[2] The costs in this column show only certain OES-administered disaster costs, such as individual and household, Public Assistance, Fire Management Assistance Grants, and Community Disaster Assistance Act costs, together with certain Small Business Act and individual and Household costs. These reflect only a portion of total disaster costs when taking into account other government-funded housing, transportation, and economic development costs, plus insurance and business interruption costs. Totals are unadjusted for inflation to 2009 dollars.

[3] Costs adjusted to 2009 dollars using the gross Domestic Product Implicit Price Deflator method.

[4] The death toll varies by 1 from previously stated source document.

[5] DR-1498, the 2003 southern California Fires, caused the elimination of vegetation securing soils to the hillsides. In December 2003, mild flooding caused mudflows and landslides, killing 16 people. The costs of the flood damages were not segregated from the fire damages.

Key:
FEMA = Federal Emergency Management Agency

1.9 Report Organization

Organization of this document is as follows:

- Section 1 describes the purpose of this attachment.
- Section 2 provides a summary of results and findings for the life risk analysis.
- Section 3 describes the methodology used in this analysis.
- Section 4 provides complete results for the life risk analysis.
- Section 5 contains references for the sources cited in this document.
- Section 6 lists abbreviations and acronyms used in this document.

2.0 Results Summary and Findings

This section summarizes the life risk values and findings for all approaches by basin.

2.1 Life Risk Values for 2012 CVFPP Approaches

Table 2-1 summarizes the estimated life risk values for the Sacramento and San Joaquin river basins, for the No Project condition and 2012 CVFPP approaches. These values are the expected annual statistics computed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA). The total life risk value for each basin is the sum of the life risk values for that basin's constituent impact areas presented in Section 4.1.

Table 2-1. Summary of Life Risk Values: Sacramento and San Joaquin River Basins and Stockton Area

CVFPP Approaches	Sacramento River Basin	San Joaquin River Basin	Stockton Area	Total
No Project Condition	58.6	4.1	1.4	64.1
Achieve SPFC Design Capacity	56.0	4.0	0.2	60.2
Protect High Risk Communities	31.6	3.9	0.2	35.7
Enhance Flood System Capacity	23.2	2.0	0.2	25.4
State Systemwide Investment	28.1	3.9	0.2	32.2

Key:
CVFPP = Central Valley Flood Protection Plan
SPFC = State Plan of Flood Control

2.2 Findings

Figure 2-1 displays the percent reductions in life risk results for the Sacramento and San Joaquin river basins and Stockton area, and all approaches studied, compared to the No Project condition. All of the approaches reduce life risk compared to the No Project condition, with the greatest reduction attributable to Enhance Flood System Capacity Approach.

The life risk values are *conditional*: they represent consequences for a given area with a specified set of hydrologic and hydraulic conditions for the system, with best representation of performance of system levees and other features, and with stated assumptions regarding public warning and response. As such, the results are informative indices of life risk, and the values shown herein provide a reliable metric for comparing the life risk reduction attributable to the proposed 2012 CVFPP approaches.

These life risk results differ from the recorded flood deaths shown in Table 1-1. This is because the LRC results shown above are planning estimates to be used as indices comparing the relative performances of the proposed 2012 CVFPP approaches in reducing flood life risk, to inform the decision making process. However, LRC results are *not* forecasts of deaths expected to occur from flood events to be used for emergency planning or other purposes; that would require much more detailed analyses and supporting data than used in the LRC.

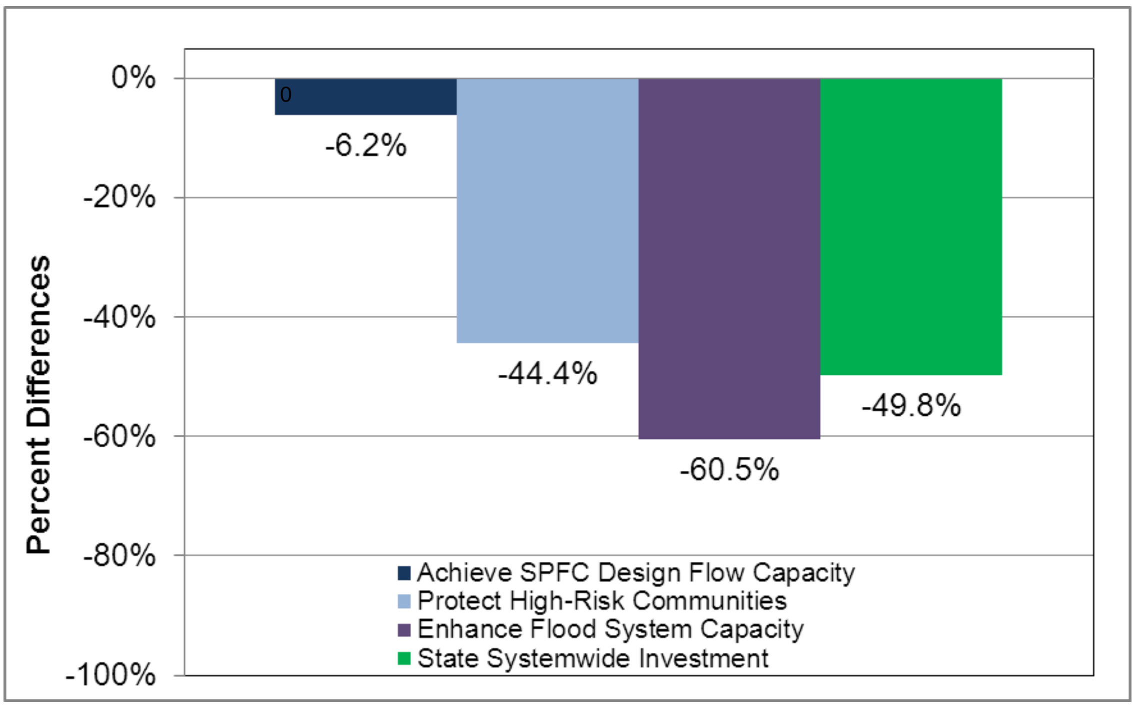


Figure 2-1. CVFPP Approach Life Risk Value Percent Reductions Compared to No Project Condition for Sacramento and San Joaquin River Basins and Stockton Area

3.0 Life Risk Analysis Method

This section presents an overview of the methods used to calculate life risk, the requirements for this analysis, a summary of existing life risk methods, the need for and description of the 2012 CVFPP LRC Method, the HEC-FDA model inputs used for this analysis, and a description of the limitation and benefits of this method.

3.1 Overview of 2012 CVFPP Life Risk Calculation Method

To inform decision making for formulation and evaluation of management options, a systematic, repeatable, rigorous method for quantifying life risk — considering the response of those in harm's way — is required. With that method, consequences of flooding in the absence of flood management actions and with various approaches can be estimated and compared.

Accordingly, the LRC Method described herein was developed and applied. This LRC Method incorporates commonly used procedures for assessing life risk, as influenced by flood hazard, system performance, and vulnerability and exposure of people. The LRC Method is tied closely to the economic risk calculations described in Attachment 8F: Flood Damage Analysis, using a common numerical description of flood hazard and levee system performance. Exposure of people is tied to exposure of property. With this analysis strategy, computations for both economic and life risk were accomplished with the USACE HEC-FDA software application.

As stated previously, the resulting life risk values are *conditional*: they represent consequences for a given area with a specified set of hydrologic and hydraulic conditions of the system, with best representation of performance of system levees and other features, and with stated assumptions regarding public warning and response. As such, the results are informative indices of life risk, and the values shown herein provide a reliable metric for *comparing* the life-risk reduction attributable to the proposed 2012 CVFPP approaches.

3.2 Requirements of 2012 CVFPP Life Risk Analysis

The 2012 CVFPP required a systematic, repeatable, and rigorous life risk analysis that does the following:

- Estimates potential life loss as a statistic that can be used as a benefit measure for comparing approaches
- Shows life loss reduction attributable to the proposed approaches due to the following:
  - Reduced flood depth
  - Reduced flood frequency
  - Reduced exposure of people to flooding
- Uses readily available data

3.3 Existing Methods for Calculating Life Risk

This subsection provides an overview of the existing methods used to calculate life risk.

3.3.1 Software Currently Available for Calculating Life Risk

Two nationally recognized software programs for calculating life risk were initially considered: LIFESim (Aboelata and Bowles, 2005) and the USACE HEC Flood Impact Analysis (HEC-FIA) program (USACE, 2004). LIFESim's development was sponsored by USACE and the Australian National Committee on Large Dams (Aboelata and Bowles, undated). The USACE HEC developed HEC-FIA.

LIFESim is a modular, spatially distributed, dynamic simulation system for estimating potential loss of life from natural and dam and levee failure flood events. LIFESim considers detailed flood dynamics, evacuation, loss of shelter, and historically based life loss.

HEC-FIA is a stand-alone software application that provides techniques for calculating post-flood or forecasted-flood impacts for a user-specified event. In addition to estimating urban and agricultural damage, HEC-FIA also estimates loss of life using methods similar to LIFESim (and, in fact, includes a simplified version of LIFESim).

Both of these software programs have intensive data requirements, and both are intended for analyses of single events. Each can be run for multiple events, and a value of expected annual fatalities can thus be computed, but time limitations of the 2012 CVFPP precluded such analyses.

3.3.2 Jonkman Method of Life Risk Estimation

S. N. Jonkman et al. (2009) devised a method to estimate potential loss of life from floods based on research into many factors that affect flood mortality. To compute life risk, Jonkman et al. followed these steps:

1. Analyze historical flood characteristics such as water depth, rise rate, and flow velocity.

2. Estimate the number of people exposed to the historical flooding, taking into account the effects of warning, evacuation, and shelter.

3. Assess mortality among those exposed to the flood.

Mortality was defined as the number of fatalities divided by the number of people exposed to flooding in a given area. Jonkman divided the inundation area into two zones: the breach zone, in which flood velocities and depths are considered, and the remaining zone, in which only depth is considered.

The mortality fraction, F_D, for the breach zone was calculated to be 0.053, indicating that approximately 5 percent of those in the breach zone will die. The mortality fraction for the remaining zone is given by Equation 1.

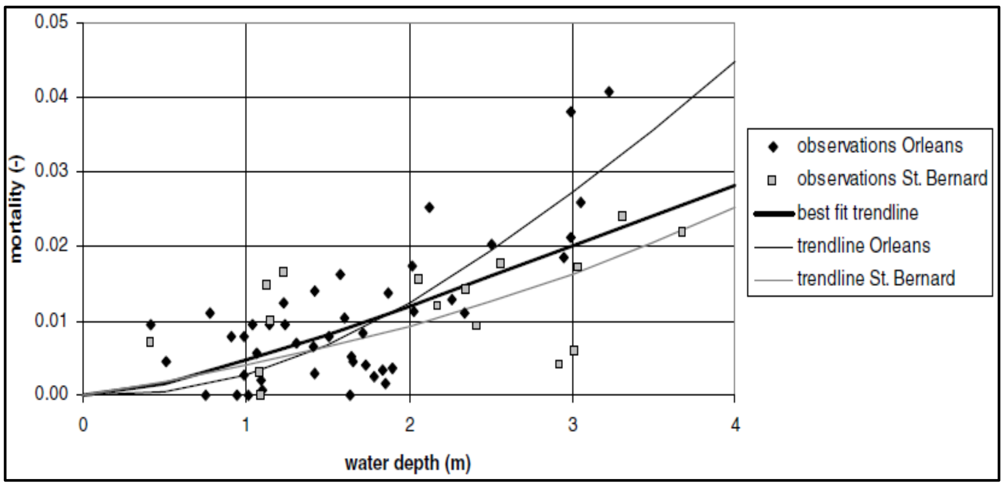
$$F_D(h)=\Phi_N\left(\frac{\ln(h)-\mu_N}{\sigma_N}\right) \qquad \text{Equation 1}$$

$\mu_N=5.20 \quad \sigma_N=2.00$

where:

$F_D(h)$ = mortality fraction as a function of water depth *h*
h = water depth (meters)
μ_N = average for the log normal distribution (meters)
σ_N = standard deviation for the log normal distribution (meters)
Φ_N = cumulative normal distribution

Figure 3-1 shows Jonkman's plot of the mortality functions (fatalities as a function of population exposed compared to flood depth) for the Orleans and St. Bernard "bowls" in New Orleans, both considered as remaining areas (i.e., areas without high flood velocities). The strong correlation between flood depth and mortality fraction evident from the figure and similar conditions in the SPFC Planning Area (i.e., significant dependence on levees for protection of floodplains) suggested that the remaining zone Equation 1 was applicable to the 2012 CVFPP life risk analysis. Although all of the CVFPP impact areas would likely contain levee breach zones, these zones of high flood velocities and depths would only apply to areas immediately adjacent to a levee breach, and not an entire impact area. An impact area is a unique, contiguous floodplain located along a stream or waterway. The SPFC Planning Area is separated into different impact areas.



Source: Jonkman, 2009

Figure 3-1. Relationship Between Water Depth and Mortality for Orleans and St. Bernard "Bowls"

3.4 Need for New Method to Satisfy 2012 CVFPP Requirements for Life Risk Analysis

None of the available methods, described above, satisfied all the requirements for the 2012 CVFPP life risk analysis, as shown in Table 3-1.

LIFESim and HEC-FIA could not be used to develop the life risk analysis in the relatively short time available for this life risk study. LIFESim requires DEM information, time series of depth grids, road network information, and vehicle databases; HEC-FIA requires digital elevation model (DEM) information and arrival time grids or hydrographs. This information was not readily available within the time frame of this study.

Table 3-1. Ability of Existing Methods to Meet 2012 CVFPP Life Risk Analysis Requirements

2012 CVFPP Life Risk Analysis Requirement	Available Method		
	LIFESim	HEC-FIA	Jonkman
Assess plan performance	✓	✓	✓
Develop and apply on schedule	X	X	✓
Use available information on loading, performance, exposure, consequences	X	X	✓
Make consistent with CVFPP economic analysis	X	X	X

Source: David Ford Consulting Engineers, Inc., 2011
Key:
X = Cannot meet CVFPP life risk analysis requirements
✓ = Can meet CVFPP life risk analysis requirements
CVFPP = Central Valley Flood Protection Plan
HEC-FIA = Hydrologic Engineering Center's Flood Impact Analysis software
LIFESim = Loss of life simulation analysis software

In addition, the two programs are intended for analysis of single events. While each can be run for multiple events, and a value of expected annual fatalities can thus be computed, the time required to complete those analyses would be excessive for the purposes of this study.

Another well-known computer program, the Federal Emergency Management Agency's (FEMA) Hazards U.S. Multi-Hazard (HAZUS-MH) software (FEMA, 2011), was not considered because it does not estimate casualties from flood events. (It does estimate casualties from earthquakes and hurricanes.)

Accordingly, a new procedure that incorporates features of the existing methods was developed and used for the 2012 CVFPP life risk analysis.

3.5 2012 CVFPP Life Risk Calculation Method

Life risk values were calculated for the No Project condition and 2012 CVFPP approaches for each of the 110 impact areas described in Attachment 8F: Flood Damage Analysis and illustrated in Figures 3-2 and 3-3. The method uses the USACE HEC-FDA software application (USACE, 2008) with nonmonetary consequence inputs.

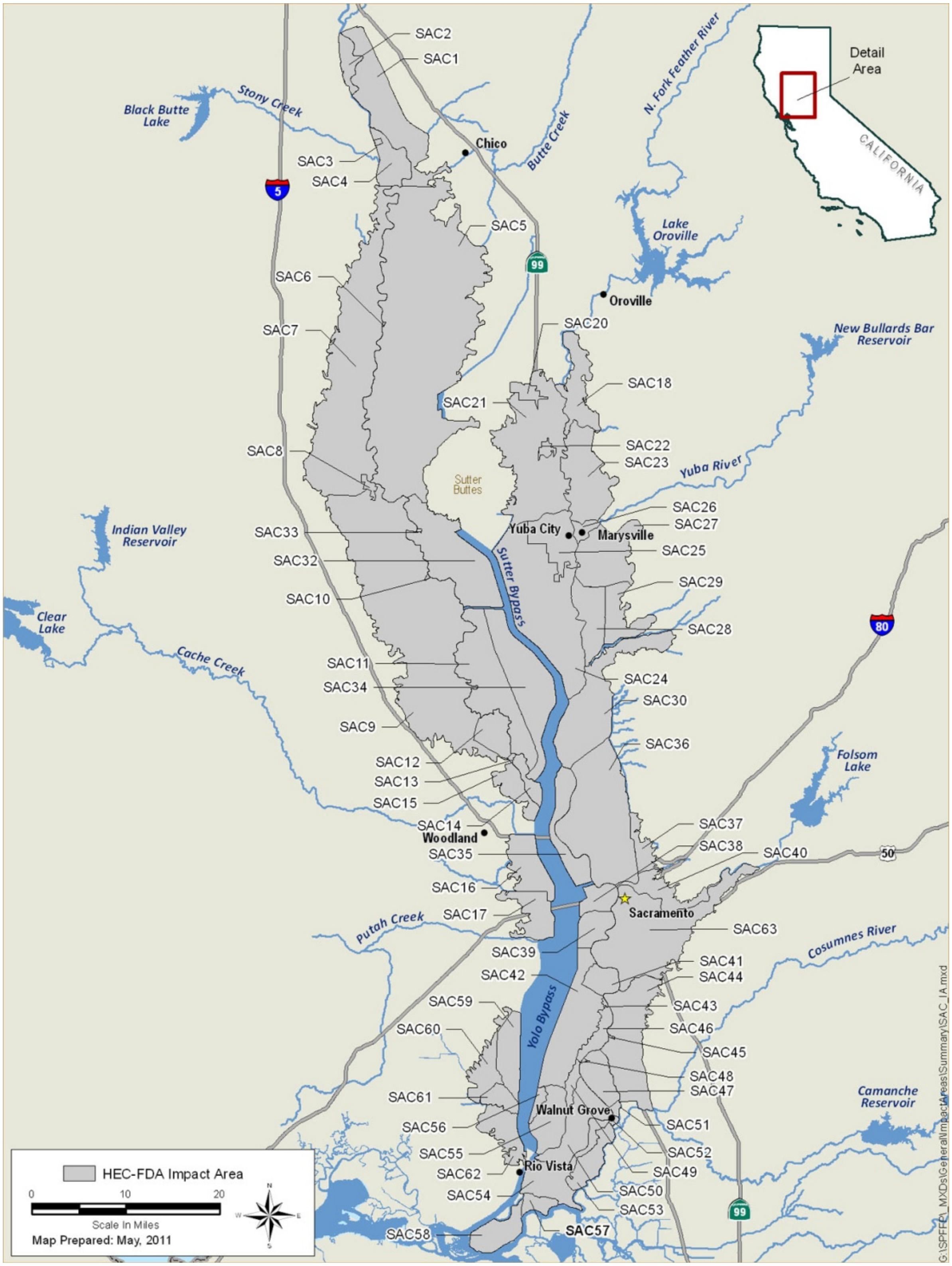


Figure 3-2. Sacramento River Basin Impact Areas

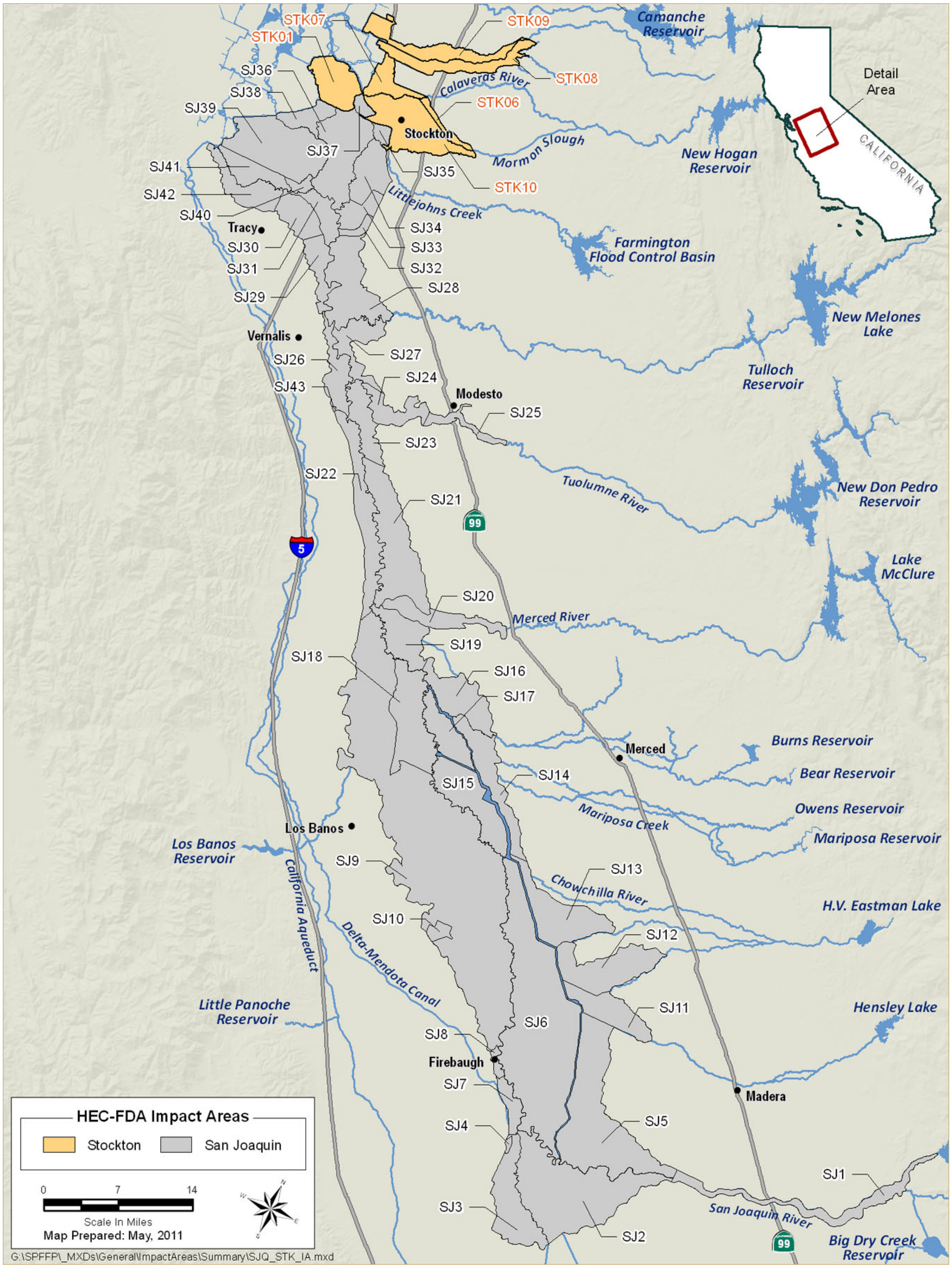


Figure 3-3. San Joaquin River Basin and Stockton Area Impact Areas

3.5.1 Summary of 2012 Life Risk Calculation Method

The 2012 LRC Method life risk analysis follows the same steps as for an economic analysis, except that the result is expected annual life risk values instead of expected annual damages. For the No Project condition and 2012 CVFPP approaches, HEC-FDA was used to complete the following actions:

1. Considering the historical record, synthesize a long series of annual maximum hydrologic and hydraulic states in a channel, inferring with standard methods the statistical properties of this loading.

2. Considering the behavior of the physical system and performance of the engineered flood management system, transform the series of hydraulic loadings of a channel to a series of depths of inundation in the impact area.

3. Transform the series of impact area loading to a series of impact area consequences, computing the annual inundation fatalities per structure, and then summing fatalities for all structures in the impact area.

4. Average the consequence to compute expected annual life risk.

HEC-FDA has the capability to incorporate uncertainty into the LRC computation using Monte Carlo simulation. This uncertainty can be described for the HEC-FDA hydraulic, geotechnical, and economic inputs. For the LRC Method, uncertainties were retained for the hydraulic and geotechnical inputs, but they were not described for the persons-per-structure relationships that replaced the structure economic values because the analysis focused on the relative differences among the No Project condition and 2012 CVFPP approaches, as shown in Figure 2-1, rather than on absolute differences.

3.5.2 2012 CVFPP Life Risk Calculation Method Procedure

The procedure in the 2012 CVFPP LRC Method consisted of the following steps:

1. For each impact area, a persons-per-structure relationship for four residential occupancy types (single family, multiple family, mobile home, and miscellaneous) was estimated. These estimates represented the “persons exposed” (in residential structures) before flood occurrence.

2. The persons-per-structure relationships determined in Step 1 were adjusted using a warning system efficiency factor to account for evacuations resulting from existing warning systems.

3. The 2012 CVFPP structure inventories were obtained for all impact areas, and residential structure economic values were replaced with adjusted persons-per-structure relationships from Step 2 to assign persons to each residential structure.

4. The revised structure inventories were imported into the 2012 CVFPP HEC-FDA models for each impact area. All other CVFPP HEC-FDA model inputs, including hydraulics (channel stage-frequency and floodplain depths) and geotechnical, were retained.

5. To compute life risk based on estimated depths at the structures, a water depth-percent mortality function was entered into HEC-FDA in place of the common depth-percent damage functions. HEC-FDA used these functions similarly to the depth-percent damage functions typically used for expected annual damage computation.

6. HEC-FDA computed expected annual life risk values for the No Project condition and the 2012 CVFPP approaches.

3.6 HEC-FDA Model Inputs and Functions for 2012 CVFPP Life Risk Calculation

The inputs and functions required for the LRC Method are as follows:

- Persons-per-structure function
- Warning system efficiency factor
- Structure inventories
- Water depth-percent mortality function

3.6.1 Persons-per-Structure Function

Life risk was computed for each residential structure in each impact area, and then aggregated. For such computation, a particular number of persons needed to be assigned to each structure.

To estimate number of persons for each structure in each impact area, a persons-per-structure function was developed. (The resulting values were then reduced with a warning system efficiency factor to account for effective flood response by a proportion of the persons in each structure.)

Data Source for Persons-per-Structure Relationship

Census tract information from the 2000 U.S. Census database was used to determine the unadjusted persons-per-structure relationship, consistent with other CVFPP analyses (U.S. Census Bureau, 2001). (The 2010 Census data were not yet complete at the time of the analysis.)

Geographic information system (GIS) tools were used to identify relevant census tracts for the analysis, starting with a TIGER/Line® shape file for each census tract, available on the U.S. Census Bureau's Web site. By intersecting (overlaying) the shape file with a GIS delineation of the impact areas, the census tracts that intersected each of the 110 impact areas were identified. Using this information, the number of people and number of structures for each census tract that intersected an impact area were obtained. Figure 3-4 shows an example analysis in which an impact area has been overlaid on census blocks; some census blocks are entirely within the impact area, whereas for others, only a portion lies within the impact area.

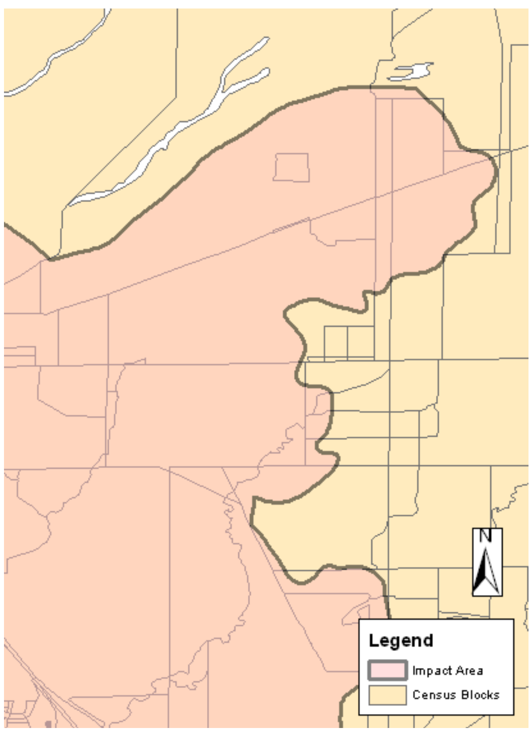


Figure 3-4. Example of Census Tracts Intersecting an Impact Area

Development of Persons-per-Structure Relationship

A persons-per-structure relationship for each of the 104 impact areas was developed for four residential occupancy types:

- SFR – single-family residence
- MFR – multiple-family residence
- MH – mobile home
- MISC-RES – miscellaneous residence
- The persons-per-structure relationship is a function of the estimated persons-per-housing unit for each occupancy type and the estimated number of housing units of each occupancy type.

Persons-per-Housing Unit To calculate persons-per-housing unit, the total number of housing units was determined by occupancy type using Table 32 of the 2000 Census database (U.S. Census Bureau, 2001), "Tenure (owner and renter) by Occupied Units in Structure," as follows:

- For SFR, the total number of housing units was determined using owner-occupied and renter-occupied, attached and detached, single-housing units for each census tract that intersected an impact area.
- For MFR, the total number of housing units was determined using owner-occupied and renter-occupied multihousing units, for all groups of multiple units (e.g., 2, 3, or 4; 5 to 9) for each census tract that intersected an impact area.
- For MH, the total number of housing units was determined using owner-occupied and renter-occupied mobile home units for each census tract that intersected an impact area.

The total population was calculated by occupancy type using Table 33 from the 2000 Census database (U.S. Census Bureau, 2001), "Total population in occupied housing units by tenure (owner and renter) by units in structure," as follows:

- For SFR, both the owner-occupied and renter-occupied attached and detached single-housing residents for each census tract that intersected an impact area were totaled.

- For MFR, both the owner-occupied and renter-occupied multihousing residents for each census tract that intersected an impact area were totaled.

- For MH, both the owner-occupied and renter-occupied mobile home residents for each census tract that intersected an impact area were totaled.

To calculate persons-per-housing unit for each impact area, the total population for each residential occupancy type was divided by the total number of housing units for that residential occupancy type to obtain persons-per-housing unit.

Persons-per-Structure
To obtain persons-per-structure, the persons-per-housing unit estimates were multiplied by the number of units for that occupancy type: 1 for SFR and MH, and the median number of units for MFR. For MISC-RES, the total population was divided by the total number of housing units for both residential occupancy types (SFR and MFR). Persons-per-structure results are shown in Tables 3-2 and 3-3. Results in these tables have not been adjusted to account for residents who will respond to a flood warning and evacuate.

3.6.2 Flood Warning Efficiency Factor

For the LRC Method, a flood warning efficiency factor is applied to reduce the population exposed because of people's response to flood warning. For this life risk study, Equation 2 of the Enhanced Flood Response and Emergency Preparedness Initial Project Feasibility Study from the Sacramento and San Joaquin River Basins Comprehensive Study (Comprehensive Study) (USACE, 2003) was used. The Comprehensive Study's use of Equation 2 to predict flood warning efficiency in the Central Valley suggested that it was applicable for this life risk study, as well.

$$eff=F_{rw}*F_w*F_c \qquad \text{Equation 2}$$

where:

eff = efficiency of flood warning
F_{rw} = fraction of the public that receives warning
F_w = fraction of the public that is willing to respond
F_c = fraction of the public that knows how to respond effectively and is capable of responding (with or without assistance)

Table 3-2. Unadjusted Persons-per-Structure Relationships for Sacramento River Basin Impact Areas

Impact Area	SFR	MFR	MH	MISC-RES
SAC01	2.82	9.39	2.57	2.79
SAC02	2.84	10.53	2.67	2.85
SAC03	3.41	11.33	3.38	3.39
SAC04	3.08	11.67	3.04	3.09
SAC05	2.95	8.73	2.68	2.92
SAC06	2.70	1.75	2.98	2.70
SAC07	2.99	8.63	2.85	2.94
SAC08	2.88	0.00	2.36	2.87
SAC09	3.09	18.94	3.09	3.04
SAC10	3.13	11.96	3.20	3.17
SAC11	3.11	10.75	3.18	3.11
SAC12	2.97	20.35	3.07	2.96
SAC13	2.97	20.35	3.07	2.96
SAC14	2.83	9.74	3.16	2.83
SAC15	2.86	7.60	3.27	2.82
SAC16	3.08	14.44	3.12	2.65
SAC17	2.82	14.44	3.12	2.65
SAC18	3.11	9.08	2.45	3.07
SAC20	3.01	0.65	2.26	2.94
SAC21	3.10	8.60	2.21	3.05
SAC22	3.39	10.71	1.90	3.36
SAC23	2.91	7.79	2.25	2.77
SAC24	3.07	9.59	2.60	3.05
SAC25	2.99	16.54	2.38	2.84
SAC26	2.96	18.11	2.29	2.85
SAC27	3.12	9.39	2.54	3.03
SAC28	3.18	11.33	2.96	3.19
SAC29	2.97	5.79	2.61	2.96
SAC30	2.98	13.53	2.54	3.01
SAC32	3.01	9.72	2.86	2.98
SAC33	2.70	15.05	2.85	2.85
SAC34	2.97	20.35	3.07	2.96
SAC35	2.97	21.09	2.58	2.97

Table 3-2. Unadjusted Persons-per-Structure Relationships for Sacramento River Basin Impact Areas (contd.)

Impact Area	SFR	MFR	MH	MISC-RES
SAC36	2.98	15.60	2.29	2.69
SAC37	3.31	22.42	2.76	3.29
SAC38	2.86	29.87	1.94	2.54
SAC39	2.54	15.70	1.96	2.46
SAC40	2.83	14.67	2.06	2.60
SAC 41	2.82	15.06	2.47	2.67
SAC42	2.65	15.12	2.33	2.59
SAC43	2.89	20.84	2.47	2.90
SAC44	3.27	36.30	2.55	3.17
SAC45	2.89	20.84	2.47	2.90
SAC46	2.81	10.45	2.68	2.82
SAC47	2.81	10.45	2.68	2.82
SAC48	2.85	10.55	2.78	2.87
SAC49	2.71	17.80	2.29	2.68
SAC50	2.64	17.25	2.12	2.61
SAC51	2.70	10.35	2.68	2.73
SAC52	2.70	10.35	2.68	2.73
SAC53	2.48	14.43	2.20	2.39
SAC54	2.69	9.40	2.18	2.69
SAC55	2.65	17.48	2.27	2.63
SAC56	2.61	16.29	1.98	2.57
SAC57	2.53	8.04	2.00	2.49
SAC58	2.53	8.04	2.00	2.49
SAC59	2.53	8.04	2.00	2.49
SAC60	2.72	16.91	2.66	2.69
SAC61	2.72	16.91	2.66	2.69
SAC62	2.61	16.29	1.98	2.57
SAC63	2.83	14.67	2.06	2.60

Source: David Ford Consulting Engineers, Inc., 2011
Key:
MFR = multiple-family residential unit
MH = mobile home unit
MISC-RES = miscellaneous residential unit
SAC = Sacramento River basin impact area
SFR = single-family residential unit

Table 3-3. Unadjusted Persons-per-Structure Relationships for San Joaquin River Basin Impact Areas

Impact Area	SFR	MFR	MH	MISC-RES
SJ01	2.97	15.24	2.88	2.86
SJ02	3.28	24.05	3.43	3.29
SJ03	3.25	21.71	3.60	3.24
SJ04	3.20	19.94	2.80	3.17
SJ05	3.33	16.47	3.54	3.37
SJ06	3.43	25.35	3.78	3.45
SJ07	3.41	25.39	3.79	3.43
SJ08	4.00	25.25	3.66	3.93
SJ09	3.39	21.67	2.93	3.36
SJ10	3.41	21.77	3.10	3.39
SJ11	3.19	11.09	3.12	3.19
SJ12	3.35	15.90	3.24	3.40
SJ13	3.36	15.90	3.26	3.39
SJ14	3.36	0.00	3.31	3.36
SJ15	3.23	20.03	2.76	3.20
SJ16	3.18	9.28	2.73	3.15
SJ17	3.12	9.15	2.78	3.08
SJ18	3.26	9.61	2.67	3.25
SJ19	3.15	9.62	2.60	3.13
SJ20	3.47	19.76	2.90	3.44
SJ21	3.24	11.34	2.77	3.24
SJ22	3.19	10.12	2.70	3.17
SJ23	3.28	12.17	3.17	3.28
SJ24	3.56	7.11	2.92	3.56
SJ25	3.44	9.21	2.55	3.33
SJ26	3.11	11.87	3.15	3.12
SJ27	3.12	9.45	2.54	3.03
SJ28	3.08	15.32	2.90	3.02
SJ29	2.94	5.75	2.78	2.94
SJ30	3.29	6.62	3.05	3.29
SJ31	2.81	5.75	2.78	2.81
SJ32	3.26	8.05	2.83	3.19
SJ33	3.07	46.25	3.46	3.08
SJ34	3.49	7.35	4.00	3.50
SJ35	3.75	14.05	2.52	3.77
SJ36	3.75	14.05	2.52	3.77

Table 3-3. Unadjusted Persons-per-Structure Relationships for San Joaquin River Basin Impact Areas (contd.)

Impact Area	SFR	MFR	MH	MISC-RES
SJ37	3.24	16.03	2.94	3.39
SJ38	3.35	6.17	2.30	3.34
SJ39	3.35	6.17	2.30	3.34
SJ40	3.23	6.04	2.34	3.22
SJ41	3.29	6.62	3.05	3.29
SJ42	3.22	6.23	3.00	3.16
SJ43	3.56	6.43	3.48	3.54

Source: David Ford Consulting Engineers, Inc., 2011
Key:
MFR = multiple-family residential unit
MH = mobile home unit
MISC-RES = miscellaneous residential unit
SFR = single-family residential unit
SJ = San Joaquin River basin impact area

Table 3-4. Unadjusted Persons-per-Structure Relationships for Stockton Area (STK) Impact Areas

Impact Area	SFR	MFR	MH	MISC-RES
STK 01	3.35	6.17	2.30	3.34
STK 06	3.21	11.64	2.35	3.21
STK 07	2.85	34.51	2.08	2.71
STK 08	3.31	10.06	2.11	3.23
STK 09	3.10	11.85	2.32	3.13
STK 10	3.23	19.11	2.60	3.12

Source: David Ford Consulting Engineers, Inc., 2011

Key:
MFR = Multi-family residential unit
MH = Mobile home unit
MISC-RES = Miscellaneous residential unit
SFR = Single-family residential unit
STK = Stockton region impact area

In the life risk study described herein, the result of Equation 2, the flood warning efficiency factor (eff), was used to adjust the persons-per-structure relationship to account for a reduction in exposure attributable to the State/federal/local warning system. In this study, variables in the equation were assigned values as follows:

- F_{rw}: Equations developed by Sorensen and Mileti (1988), shown in Table 3-5, were used to determine F_{rw}.

- F_w: The Comprehensive Study value of 1.00, derived from an expert elicitation, was used.

- F_c: Comprehensive Study value of 0.70, derived from an expert elicitation, was used.

These variables are described in greater detail below.

Value of Fraction of Public That Receives Warning (F_{rw})

To assign a value to F_{rw}, Sorensen and Mileti (1988) assessed the importance of two factors: the fraction of people at risk who could possibly be warned in a given time, and the fraction of people who will evacuate when ordered or advised to do so. In a comparative analysis of two dozen studies on public evacuation, the authors concluded that the number of people who will receive a warning increases as the available warning time increases. Sorensen and Mileti developed the equations in Table 3-5 to predict the fraction of public warned. The equations in Table 3-5 were used in the 2012 CVFPP life risk analysis.

Table 3-5. Fraction of Public Warned Given Available Warning Time

Available Warning Time	Equation, where *X* = available warning time (hours)
Available warning time < 0.8 hours (50 minutes)	Percent warned = $81.83(X)^{3.488}$
0.8 hours ≤ available warning time < 3 hours	Percent warned = $59.58(X)^{0.4753}$
3 hours ≤ available warning time < 7 hours	Percent warned = $66.63(X)^{0.2089}$
Available warning time ≥ 7 hours	Percent warned = 100

Source: Sorensen and Mileti, 1988

Sorensen and Mileti suggested that the evacuation rate (the fraction of people who leave the hazardous area) ranges from 0.32 to 0.98. Evacuation rates under conditions of perceived high risk ranged from 0.4 to 1.00.

The Comprehensive Study impact areas are nearly identical to the impact areas for the 2012 CVFPP. Therefore, the without-project warning times provided in the Comprehensive Study were used in the Sorensen and Mileti equations in this life risk analysis. (Note that the Comprehensive Study used the term “mitigation time” for the period of time that this life risk study refers to as “warning time.”) Attachment A provides information on how the Comprehensive Study warning times were determined.

In this life risk study, the differences in the impact areas were accounted for as follows: (1) the Comprehensive Study did not include Impact Area SAC63, so the Comprehensive Study Impact Area SAC40 was divided into two impact areas (SAC40 and SAC63) for this study, (2) the

Comprehensive Study did not include a warning time for Impact Area SJ40, so the warning time for the surrounding areas was used for SJ40, and (3) the Comprehensive Study did not include a warning time for Impact Area SJ43, so the warning time for SJ26, located just downstream from SJ43, was used here.

A final change involved Impact Area SAC36, Natomas. Although this impact area is located along the left bank of the Sacramento River (just upstream of Sacramento), the warning time developed for the Comprehensive Study (0 hours) is primarily influenced by the local streams along the northern and eastern boundaries, and the American River to the south. However, for purposes of the SAC36 HEC-FDA model, flooding is assumed to occur from the Sacramento River. Thus, a warning time was used from an impact area directly across the Sacramento River from SAC36: SAC35 (Elkhorn). This time is 21 hours, which reflects the downstream location of SAC35 and SAC36 along the Sacramento River.

Comprehensive Study Sacramento River basin warning times are listed in Table 3-6, and Comprehensive Study San Joaquin River basin warning times are listed in Table 3-7. Appendix A provides information on how the Comprehensive Study warning times were determined.

Comprehensive Study warning times were not developed for the Stockton region. Thus, warning times for Stockton region impact areas were assigned based upon warning times in other San Joaquin and Sacramento impact areas with similar flood sources, as simulated within the HEC-FDA models. For example, STK 01 (Lower Roberts Island) floods from the San Joaquin River, thus a mitigation time from nearby impact areas along the San Joaquin River was used: 36 hours. For all of the other Stockton impact areas, flooding occurs from local streams with potentially much shorter warning times, thus a warning time from SAC 40 and SAC 63 along the American River was used: 0 hours. Stockton region mitigation times are shown in Table 3-8.

Value of Fraction of Public That Is Willing to Respond to Warning (F_w)

Comprehensive Study experts suggested that F_w is close to 1.00. The experts argued that, in the Central Valley, a floodplain occupant who receives a credible warning is willing to take some kind of action. For purposes of the 2012 CVFPP, ongoing flood awareness activities by State and local governments throughout the Central Valley justify the value of 1.00 for F_w. For example, the DWR Flood Risk Notification Program, which is part of the DWR FloodSAFE California initiative, is overseeing several activities to increase flood awareness in the Central Valley. Whether or not the actions taken are effective at reducing consequence is taken into account in F_c.

Value of Fraction of Public That Knows How to Respond Effectively and Is Capable of Responding (with or without assistance) (F_c)
Comprehensive Study experts suggested that F_c ranges from 0.50 to 1.00, with an average of 0.70. This value falls within the range from Sorensen and Mileti (0.32 to 0.98).

3.6.3 Adjusted Persons-per-Structure Values

The unadjusted persons-per-structure values provided in Tables 3-2 and 3-3 were adjusted to account for the fraction of floodplain occupants who will respond effectively and evacuate. The adjustment was made for each impact area and applied to the four residential occupancy types using Equation 3.

$$PPS_{ADJ}=(1-eff)*PPS \qquad \text{Equation 3}$$

where:

eff = efficiency of flood warning (from Equation 2)
PPS = unadjusted persons-per-structure
PPS_{ADJ} = adjusted persons-per-structure

Table 3-6. Comprehensive Study No Project Condition Warning (Mitigation) Times for Sacramento River Basin Impact Areas

Impact Area	Description	Warning Time (hour)	Impact Area	Description	Warning Time (hour)
SAC01	Woodson Bridge East	0	SAC34	RD 1500 East	4
SAC02	Woodson Bridge West	6	SAC35	Elkhorn	21
SAC03	Hamilton City	0	SAC36	Natomas	21[1]
SAC04	Capay	0	SAC37	Rio Linda	0
SAC05	Butte Basin	3	SAC38	West Sacramento	0
SAC06	Butte City	3	SAC39	RD 900	24
SAC07	Colusa Basin North	7	SAC40	Sacramento North	0
SAC08	Colusa	13	SAC41	RD 302	24
SAC09	Colusa Basin South	19	SAC42	RD 999	24
SAC10	Grimes	16	SAC43	Clarksburg	24
SAC11	RD 1500 West	4	SAC44	Stone Lake	24
SAC12	Sycamore Slough	21	SAC45	Hood	24
SAC13	Knight's Landing	21	SAC46	Merritt Island	24
SAC14	Ridge Cut (North)	21	SAC47	RD 551	24
SAC15	Ridge Cut (South)	21	SAC48	Courtland	24
SAC16	RD 2035	21	SAC49	Sutter Island	27
SAC17	East of Davis	21	SAC50	Grand Island	27
SAC18	Upper Honcut	0	SAC51	Locke	27
SAC20	Gridley	0	SAC52	Walnut Grove	27
SAC21	Sutter Buttes East	0	SAC53	Tyler Island	27
SAC22	Live Oak	0	SAC54	Andrus Island	27
SAC23	Lower Honcut	0	SAC55	Ryer Island	27
SAC24	Levee District #1	0	SAC56	Prospect Island	27
SAC25	Yuba City	0	SAC57	Twitchell Island	27
SAC26	Marysville	0	SAC58	Sherman Island	27
SAC27	Linda-Olivehurst	0	SAC59	Moore	27
SAC28	RD 784	0	SAC60	Cache Slough	27
SAC29	Best Slough	0	SAC61	Hastings	27
SAC30	RD 1001	0	SAC62	Lindsey Slough	27
SAC32	RD 70-1660	0	SAC63	Sacramento South	0[2]
SAC33	Meridian	0			

Source: USACE, 2003
Notes:
[1] This time was obtained from SAC36 (Elkhorn).
[2] Comprehensive Study did not include impact area SAC63. The original SAC40 was divided into two impact areas (SAC40 and SAC63) for this study and the same mitigation time as for the original SAC40 was used for both.
Key: RD = Reclamation District; SAC = Sacramento River basin impact area

Table 3-7. Comprehensive Study No Project Condition Warning (Mitigation) Times for San Joaquin River Basin (SJ) Impact Areas

Impact Area	Description	Warning Time (hour)	Impact Area	Description	Warning Time (hour)
SJ01	Fresno	0	SJ23	Tuolumne South	0
SJ02	Fresno Slough East	0	SJ24	Tuolumne River	0
SJ03	Fresno Slough West	0	SJ25	Modesto	0
SJ04	Mendota	0	SJ26	Three Amigos	24
SJ05	Chowchilla Bypass	0	SJ27	Stanislaus South	0
SJ06	Lone Willow Slough	0	SJ28	Stanislaus North	3
SJ07	Mendota North	0	SJ29	Banta Carbona	36
SJ08	Firebaugh	0	SJ30	Paradise Cut	36
SJ09	Salt Slough	15	SJ31	Stewart Tract	36
SJ10	Dos Palos	9	SJ32	East Lathrop	36
SJ11	Fresno River	0	SJ33	Lathrop/Sharpe	36
SJ12	Berenda Slough	0	SJ34	French Camp	36
SJ13	Ash Slough	0	SJ35	Moss Tract	36
SJ14	Sandy Mush	15	SJ36	Roberts Island	36
SJ15	Turner Island	15	SJ37	Rough and Ready Island	36
SJ16	Bear Creek	33	SJ38	Drexler Tract	36
SJ17	Deep Slough	24	SJ39	Union Island	36
SJ18	West Bear Creek	24	SJ40	Union Island Toe	36[1]
SJ19	Fremont Ford	33	SJ41	Fabian Tract	36
SJ20	Merced River	33	SJ42	RD 1007	36
SJ21	Merced River North	30	SJ43	Grayson	24[2]
SJ22	Orestimba	30			

Source: USACE, 2003

Notes:

[1] Comprehensive Study did not include a mitigation time for Impact Area SJ40, so David Ford Consulting Engineers used the same mitigation time as the surrounding impact areas.

[2] Comprehensive Study did not include a mitigation time for impact area SJ43; therefore, David Ford Consulting Engineers used the same mitigation time as from Impact Area SJ26, which is just downstream from SJ43.

Key:

RD = Reclamation District

SJ = San Joaquin River basin impact area

Table 3-8. Assigned No Project Warning (Mitigation) Times for Stockton Area (STK) Impact Areas

Impact Area	Description	Warning Time (hr)	Impact Area	Description	Warning Time (hr)
STK 01	Lower Roberts Island[1]	36	STK 08	Bear Creek South[2]	0
STK 06	Stockton East[2]	0	STK 09	Bear Creek North[2]	0
STK 07	Calaveras River[2]	0	STK 10	Central Stockton[2]	0

Notes:
[1] The Comprehensive Study did not include mitigation times for the Stockton area, thus a mitigation time for STK01 was obtained from surrounding impact areas along San Joaquin River.
[2] A mitigation time for the other Stockton impact areas, with flooding from local sources, was obtained from SAC 40 and SAC 63 along the American River.
Key:
hr = hour
STK= Stockton region impact area

The adjusted persons-per-structure values for the impact areas are listed in Tables 3-9 and 3-11. In many impact areas, the flood warning system efficiency is 0.00 because the warning times are 0.00. As a result, there is no reduction in the unadjusted persons-per-structure relationships for these impact areas shown in Tables 3-2 and 3-3.

3.6.4 Water Depth-Percent Mortality Function

Jonkman’s (2009) remaining zone water depth-percent mortality relationship (Equation 1 above) was used to calculate the 2012 CVFPP LRC Method water depth-percent mortality results shown in Table 3-12.

3.6.5 Other Inputs to 2012 CVFPP Life Risk Calculation Model

The HEC-FDA models developed for the economic evaluation of flood damages were modified as noted below for this life risk analysis. These HEC-FDA models required the following inputs:

- Stage-frequency curve (stream hydraulics and hydrology)
- Levee fragility curve (geotechnical considerations)
- Flood depth grid (floodplain hydraulics)

For this life risk analysis, the economic information necessary to compute expected annual damages was replaced with persons-per-structure functions and water depth-percent mortality functions, as described earlier in this report.

Table 3-9. Adjusted Persons-per-Structure Relationships for Sacramento River Basin Impact Areas

Impact Area	Flood Warning Efficiency	SFR	MFR	MH	MISC-RES
SAC01	0.00	2.82	9.39	2.57	2.79
SAC02	67.81	0.91	3.37	0.85	0.91
SAC03	0.00	3.41	11.33	3.38	3.39
SAC04	0.00	3.08	11.67	3.04	3.09
SAC05	58.67	1.21	3.58	1.10	1.20
SAC06	58.67	1.11	0.72	1.22	1.11
SAC07	70.00	0.90	2.59	0.85	0.88
SAC08	70.00	0.86	0.00	0.71	0.86
SAC09	70.00	0.93	5.68	0.93	0.91
SAC10	70.00	0.94	3.59	0.96	0.95
SAC11	62.31	1.18	4.09	1.21	1.18
SAC12	70.00	0.89	6.10	0.92	0.89
SAC13	70.00	0.89	6.10	0.92	0.89
SAC14	70.00	0.85	2.92	0.95	0.85
SAC15	70.00	0.86	2.28	0.98	0.85
SAC16	70.00	0.92	4.33	0.93	0.79
SAC7	70.00	0.85	4.33	0.93	0.79
SAC18	0.00	3.11	9.08	2.45	3.07
SAC20	0.00	3.01	0.65	2.26	2.94
SAC21	0.00	3.10	8.60	2.21	3.05
SAC22	0.00	3.39	10.71	1.90	3.36
SAC23	0.00	2.91	7.79	2.25	2.77
SAC24	0.00	3.07	9.59	2.60	3.05
SAC25	0.00	2.99	16.54	2.38	2.84
SAC26	0.00	2.96	18.11	2.29	2.85
SAC27	0.00	3.12	9.39	2.54	3.03
SAC28	0.00	3.18	11.33	2.96	3.19
SAC29	0.00	2.97	5.79	2.61	2.96
SAC30	0.00	2.98	13.53	2.54	3.01
SAC32	0.00	3.01	9.72	2.86	2.98
SAC33	0.00	2.70	15.05	2.85	2.85
SAC34	62.31	1.13	7.73	1.17	1.12

Table 3-9. Adjusted Persons-per-Structure Relationships for Sacramento River Basin Impact Areas (contd.)

Impact Area	Flood Warning Efficiency	SFR	MFR	MH	MISC-RES
SAC35	70.00	0.89	6.33	0.77	0.89
SAC36	70.00[1]	0.89	4.68	0.69	0.81
SAC37	0.00	3.31	22.42	2.76	3.29
SAC38	0.00	2.86	29.87	1.94	2.54
SAC39	70.00	0.76	4.71	0.59	0.74
SAC40	0.00	2.83	14.67	2.06	2.60
SAC41	70.00	0.84	4.52	0.74	0.80
SAC42	70.00	0.79	4.53	0.70	0.78
SAC43	70.00	0.87	6.25	0.74	0.87
SAC44	70.00	0.98	10.89	0.76	0.95
SAC45	70.00	0.87	6.25	0.74	0.87
SAC46	70.00	0.84	3.14	0.80	0.85
SAC47	70.00	0.84	3.14	0.80	0.85
SAC48	70.00	0.86	3.17	0.83	0.86
SAC49	70.00	0.81	5.34	0.69	0.81
SAC50	70.00	0.79	5.17	0.64	0.78
SAC51	70.00	0.81	3.10	0.81	0.82
SAC52	70.00	0.81	3.10	0.81	0.82
SAC53	70.00	0.74	4.33	0.66	0.72
SAC54	70.00	0.81	2.82	0.65	0.81
SAC55	70.00	0.80	5.24	0.68	0.79
SAC56	70.00	0.78	4.89	0.59	0.77
SAC57	70.00	0.76	2.41	0.60	0.75
SAC58	70.00	0.76	2.41	0.60	0.75
SAC59	70.00	0.76	2.41	0.60	0.75
SAC60	70.00	0.82	5.07	0.80	0.81
SAC61	70.00	0.82	5.07	0.80	0.81
SAC62	70.00	0.78	4.89	0.59	0.77
SAC63	0.00	2.83	14.67	2.06	2.60

Source: David Ford Consulting Engineers, Inc., 2011
Notes:
[1] Based on mitigation time of 21 hours obtained from SAC36 (Elkhorn).
Key:
MFR = multiple-family residential unit
MH = mobile home unit
MISC-RES = miscellaneous residential unit
SFR = single-family residential unit

Table 3-10. Adjusted Persons-per-Structure Relationships for San Joaquin River Basin Impact Areas

Impact Area	Flood Warning Efficiency	SFR	MFR	MH	MISC-RES
SJ01	0.00	2.97	15.24	2.88	2.86
SJ02	0.00	3.28	24.05	3.43	3.29
SJ03	0.00	3.25	21.71	3.60	3.24
SJ04	0.00	3.20	19.94	2.80	3.17
SJ05	0.00	3.33	16.47	3.54	3.37
SJ06	0.00	3.43	25.35	3.78	3.45
SJ07	0.00	3.41	25.39	3.79	3.43
SJ08	0.00	4.00	25.25	3.66	3.93
SJ09	70.00	1.02	6.50	0.88	1.01
SJ10	70.00	1.02	6.53	0.93	1.02
SJ11	0.00	3.19	11.09	3.12	3.19
SJ12	0.00	3.35	15.90	3.24	3.40
SJ13	0.00	3.36	15.90	3.26	3.39
SJ14	70.00	1.01	0.00	0.99	1.01
SJ15	70.00	0.97	6.01	0.83	0.96
SJ16	70.00	0.95	2.79	0.82	0.95
SJ17	70.00	0.94	2.75	0.83	0.92
SJ18	70.00	0.98	2.88	0.80	0.97
SJ19	70.00	0.94	2.89	0.78	0.94
SJ20	70.00	1.04	5.93	0.87	1.03
SJ21	70.00	0.97	3.40	0.83	0.97
SJ22	70.00	0.96	3.04	0.81	0.95
SJ23	0.00	3.28	12.17	3.17	3.28
SJ24	0.00	3.56	7.11	2.92	3.56
SJ25	0.00	3.44	9.21	2.55	3.33
SJ26	70.00	0.93	3.56	0.94	0.94
SJ27	0.00	3.12	9.45	2.54	3.03
SJ28	58.67	1.26	6.28	1.19	1.24
SJ29	70.00	0.88	1.73	0.83	0.88
SJ30	70.00	0.99	1.99	0.92	0.99
SJ31	70.00	0.84	1.73	0.84	0.84
SJ32	70.00	0.98	2.42	0.85	0.96
SJ33	70.00	0.92	13.88	1.04	0.92

Table 3-10. Adjusted Persons-per-Structure Relationships for San Joaquin River Basin Impact Areas (contd.)

Impact Area	Flood Warning Efficiency	SFR	MFR	MH	MISC-RES
SJ34	70.00	1.05	2.20	1.20	1.05
SJ35	70.00	1.12	4.21	0.76	1.13
SJ36	70.00	1.12	4.21	0.76	1.13
SJ37	70.00	0.97	4.81	0.88	1.02
SJ38	70.00	1.00	1.85	0.69	1.00
SJ39	70.00	1.00	1.85	0.69	1.00
SJ40	70.00	0.97	1.81	0.70	0.97
SJ41	70.00	0.99	1.99	0.92	0.99
SJ42	70.00	0.96	1.87	0.90	0.95
SJ43	70.00	1.07	1.93	1.04	1.06

Source: David Ford Consulting Engineers, Inc., 2011
Key:
MFR = multiple-family residential unit
MH = mobile home unit
MISC-RES = miscellaneous residential unit
SFR = single-family residential unit

Table 3-11. Adjusted Persons-per-Structure Relationships for Stockton Area (STK) Impact Areas

Impact Area	SFR	MFR	MH	MISC-RES
STK 01	1.00	1.85	0.69	1.00
STK 06	3.21	11.64	2.35	3.21
STK 07	2.85	34.51	2.08	2.71
STK 08	3.31	10.06	2.11	3.23
STK 09	3.10	11.85	2.32	3.13
STK 10	3.23	19.11	2.60	3.12

Source: David Ford Consulting Engineers, Inc., 2011
Key:
MFR = multiple-family residential unit
MH = mobile home unit
MISC-RES = miscellaneous residential unit
SFR = single-family residential unit
STK = Stockton area impact area

Table 3-12. Water Depth-Percent Mortality Results

Water Depth (feet)	Percent Mortality
0	0.0
1	0.1
2	0.2
3	0.4
4	0.6
5	0.8
6	1.1
7	1.3
8	1.6
9	1.8
10	2.1
11	2.3
12	2.5
13	2.8
14	3.0
15	3.3
16	3.5
25	5.7

Source: David Ford Consulting Engineers, Inc., 2011

3.7 Limitations and Advantages of 2012 CVFPP Life Risk Calculation Method

The 2012 CVFPP LRC Method incorporates commonly used procedures for assessing life risk, as influenced by flood hazard, system performance, and vulnerability and exposure of people. The LRC Method is consistent generally with USACE methods. For consistency, the LRC Method integrated the life risk calculation method with the economic risk calculations described in Attachment 8F: Flood Damage Analysis, using a common numerical description of flood hazard and levee system performance. Exposure of people is tied to exposure of property. With this analysis strategy, computations for both economic and life risk were accomplished with the USACE HEC-FDA software application, as described above. The resulting life risk values are *conditional*: they represent consequences for a given area with a specified set of hydrologic and hydraulic conditions of the system, with best representation of performance of system levees and other features, and with stated assumptions regarding public warning and response. As such, the results are informative indices of life risk, and the values shown herein provide a reliable metric for comparing the life-risk reduction attributable to 2012 CVFPP approaches. However, the analysis is not a detailed life safety analysis suitable for other purposes, such as to forecast mortality for emergency response.

For example, the LRC Method does not account explicitly for the following:

- Changes in the distribution of people (exposure) as they respond to any flood warnings that may be issued.

- Floods arriving at different times of the day, or on different days of the week.

- Number of people who reach safety by moving to a higher elevation in a structure ("sheltering"), compared to those who are able to flee the structures and reach safety outside the flood zone.

Nevertheless, given that it is used to evaluate relative differences in life risk among different approaches for each impact area, the LRC method is appropriate for the 2012 CVFPP life risk analysis for the following reasons:

- Meets the plan evaluation objectives
- Is systematic, reproducible, and defendable
- Is based on reasonable science
- Relies on empirical data
- Relies on readily available data
- Is applicable systemwide

4.0 Results

4.1 Life Risk Results

The computed life risk values for the No Project condition and the 2012 CVFPP approaches for each impact area of the Sacramento and San Joaquin river basins, and Stockton area, are shown in Tables 4-1, 4-2, and 4-3, respectively.

4.1.1 Results for No Project Condition

The No Project condition life risk values for the Sacramento River basin range from 0 to 32.2 (Table 4-1). Impact areas with some of the higher life risk values include SAC25-Yuba City (8.2), SAC27-Linda-Olivehurst (1.2), SAC36-Natomas (2.5), SAC37-Rio Linda (1.7), SAC38-West Sacramento (2.4), SAC40-Sacramento North (7.0), and SAC63-Sacramento South (32.2). The total No Project condition life risk value for this basin is 58.6.

The variation in life risk values for the San Joaquin River basin is much less, ranging from 0 to 3.0 (Table 4-2). Impact areas with some of the higher life risk values include SJ09-Salt Slough (3.0), SJ24-Tuolumne River (0.3), SJ25-Modesto (0.2), and SJ33-Lathrop/Sharpe (0.3). The total No Project condition life risk value for this basin (4.1) is much less than the Sacramento River basin.

For the Stockton area, No Project life risk values range from 0 to 1.0 as shown in Table 4-3.

For all basins, No Project life risk values for most impact areas are less than 1.

4.1.2 Results for 2012 CVFPP Approaches

For the Sacramento River basin, all of the 2012 CVFPP approaches have lower life risk values than the No Project condition, with the greatest reduction occurring with the Enhanced Flood System Capacity Approach (23.2 compared to 58.6).

For the San Joaquin River basin, all of the 2012 CVFPP approaches have lower life risk values than the No Project condition, with the greatest reduction occurring with the Enhanced Flood System Capacity Approach (2.0 compared to 4.1).

For the Stockton area, all of the 2012 CVFPP approaches have the same components of levee improvement, except for STK01, and therefore reduce the No Project condition life risk value by the same amount (0.2 compared to 1.4). The Protect High Risk Communities Approach results were used to represent all approaches (excluding No Project), except for STK01. All approaches were estimated in STK01.

Figures 4-1, 4-2, and 4-3 show the percent life risk reductions for all approaches, compared to the No Project condition, for the Sacramento and San Joaquin river basins, and Stockton area, respectively. Tables 4-1, 4-2, and 4-3 present the life risk values for all approaches, by impact area, for the Sacramento and San Joaquin river basins, and Stockton area, respectively.

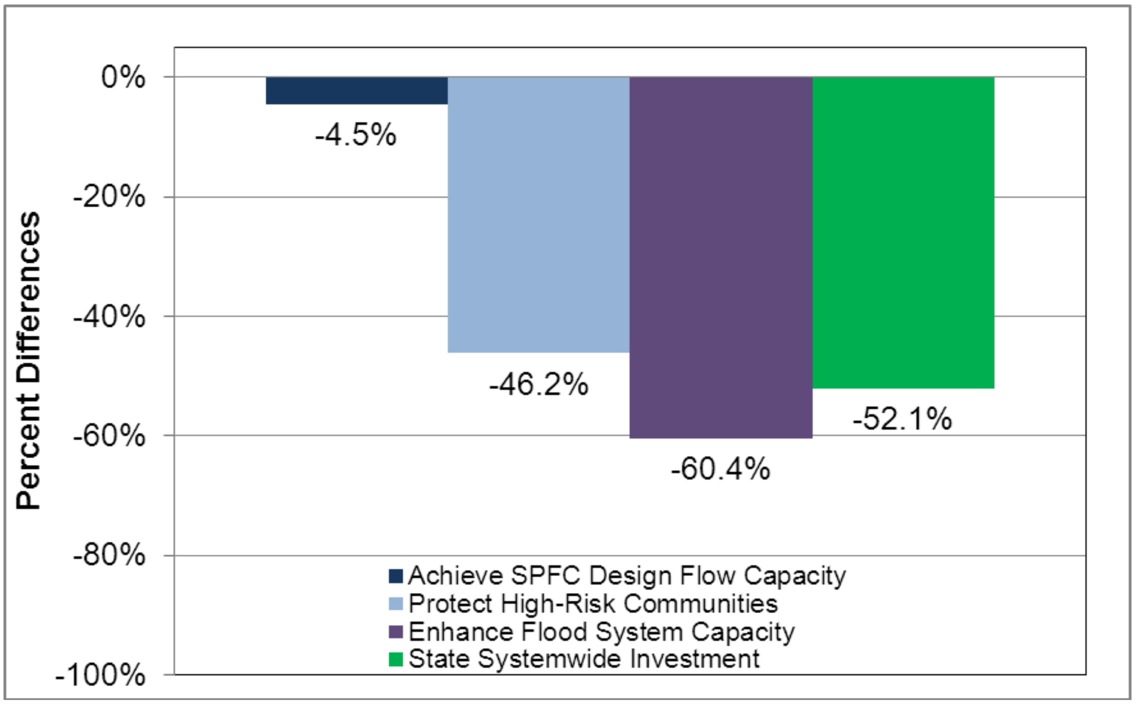


Figure 4-1. CVFPP Approach Life Risk Value Percent Reductions Compared to No Project Condition for Sacramento River Basin

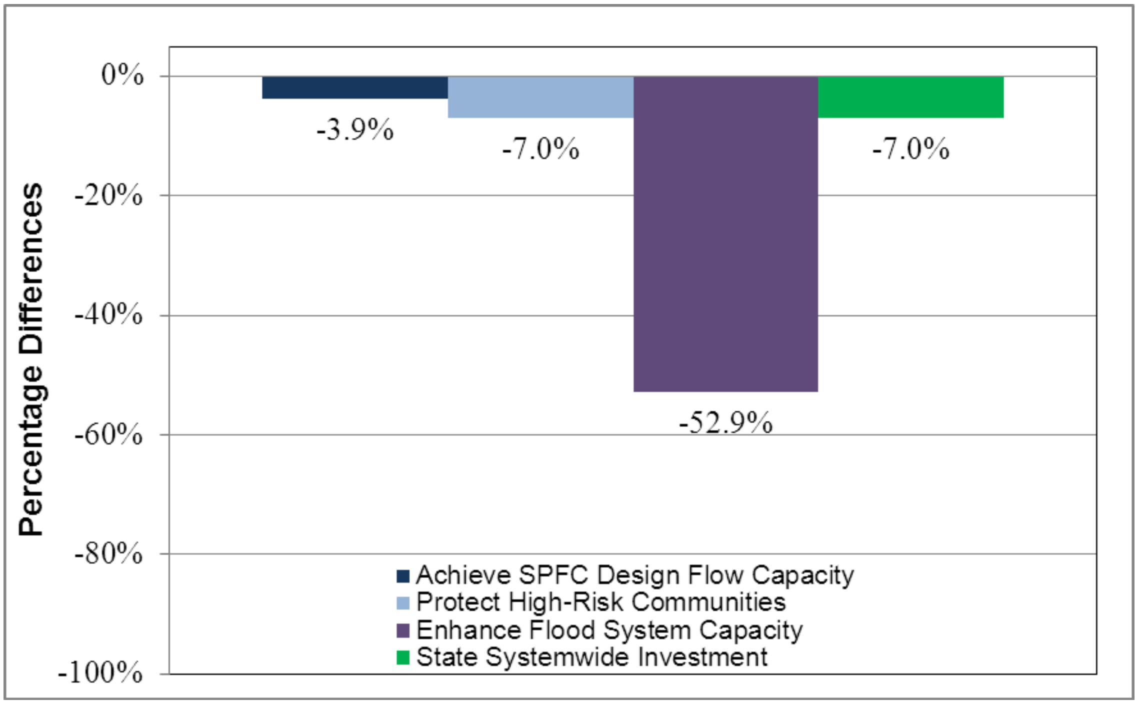


Figure 4-2. CVFPP Approach Life Risk Value Percent Reductions Compared to No Project Condition for San Joaquin River Basin

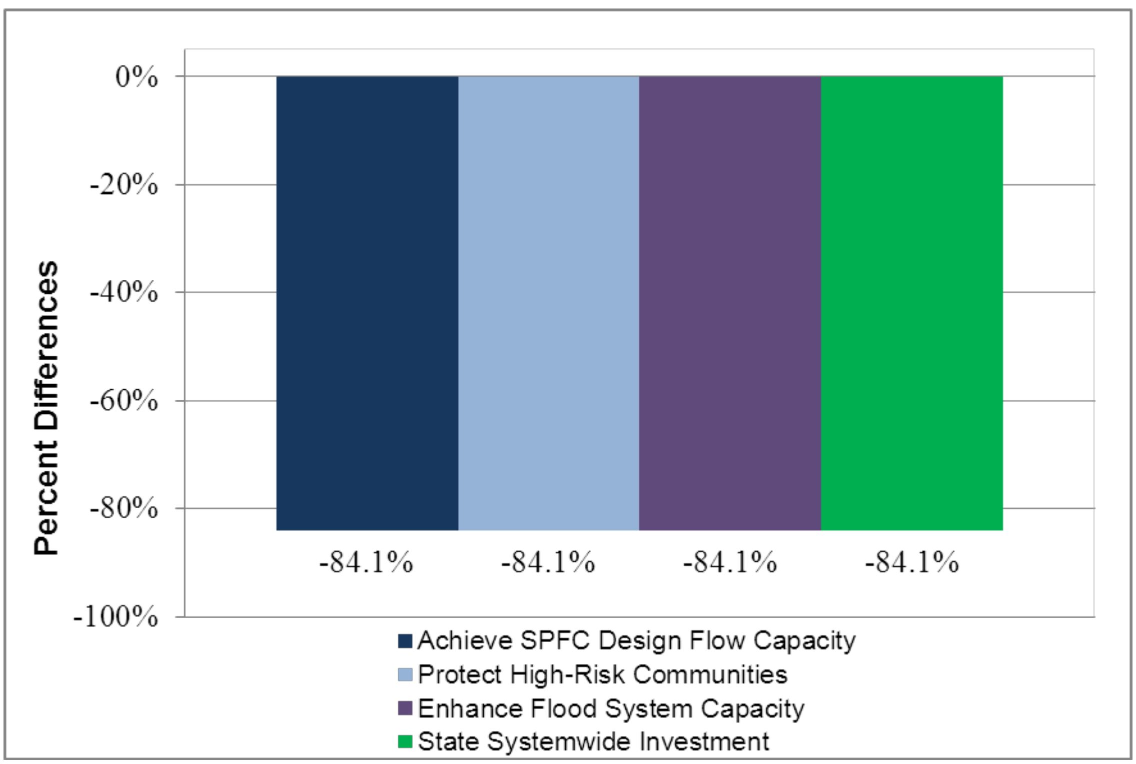


Figure 4-3. CVFPP Approach Life Risk Value Percent Reductions Compared to No Project Condition for Stockton Area

Table 4-1. 2012 CVFPP Life Risk Values for Sacramento River Basin Impact Areas

Impact Area	Description	No Project	SPFC	PHRC	EFSC	SSIA
SAC01	Woodson Bridge East	0.0	0.0	0.0	0.0	0.0
SAC02	Woodson Bridge West	0.0	0.0	0.0	0.0	0.0
SAC03	Hamilton City	0.2	0.3	0.3	0.3	0.3
SAC04	Capay	0.0	0.0	0.0	0.0	0.0
SAC05	Butte Basin	0.0	0.0	0.0	0.0	0.0
SAC06	Butte City	0.0	0.0	0.0	0.0	0.0
SAC07	Colusa Basin North	0.0	0.0	0.0	0.0	0.0
SAC08	Colusa	0.0	0.0	0.0	0.0	0.0
SAC09	Colusa Basin South	0.0	0.0	0.0	0.0	0.0
SAC10	Grimes	0.0	0.0	0.0	0.0	0.0
SAC11	RD 1500 West	0.0	0.0	0.0	0.0	0.0
SAC12	Sycamore Slough	0.0	0.0	0.0	0.0	0.0
SAC13	Knight's Landing	0.3	0.1	0.3	0.0	0.1
SAC14	Ridge Cut (North)	0.0	0.0	0.0	0.0	0.0
SAC15	Ridge Cut (South)	0.0	0.0	0.0	0.0	0.0
SAC16	RD 2035	0.0	0.0	0.0	0.0	0.0
SAC17	East of Davis	0.0	0.0	0.0	0.0	0.0
SAC18	Upper Honcut	0.0	0.0	0.0	0.0	0.0
SAC20	Gridley	0.1	0.1	0.1	0.1	0.1
SAC21	Sutter Buttes East	0.1	0.1	0.1	0.1	0.1
SAC22	Live Oak	0.2	0.3	0.2	0.2	0.2
SAC23	Lower Honcut	0.1	0.1	0.1	0.1	0.1
SAC24	Levee District #1	0.1	0.0	0.2	0.0	0.0
SAC25	Yuba City	8.2	3.4	2.7	2.5	2.4
SAC26	Marysville	0.4	0.5	0.5	0.5	0.5
SAC27	Linda-Olivehurst	1.2	1.3	1.4	1.3	1.3
SAC28	RD 784	0.4	0.8	0.5	0.2	0.4
SAC29	Best Slough	0.2	0.0	0.2	0.1	0.2
SAC30	RD 1001	0.1	0.0	0.1	0.0	0.1
SAC32	RD 70-1660	0.1	0.0	0.1	0.0	0.1
SAC33	Meridian	0.1	0.0	0.1	0.0	0.1
SAC34	RD 1500 East	0.0	0.0	0.0	0.0	0.0
SAC35	Elkhorn	0.0	0.0	0.0	0.0	0.0
SAC36	Natomas	2.5	2.9	0.7	0.6	0.8

Table 4-1. 2012 CVFPP Life Risk Values for Sacramento River Basin (SAC) Impact Areas (contd.)

Impact Area	Description	No Project	SPFC	PHRC	EFSC	SSIA
SAC37	Rio Linda	1.7	2.1	1.2	1.0	1.2
SAC38	West Sacramento	2.4	1.8	1.2	0.8	1.2
SAC39	RD 900	0.4	0.4	0.1	0.1	0.1
SAC40	Sacramento North	7.0	6.0	3.2	3.0	3.2
SAC41	RD 302	0.0	0.0	0.0	0.0	0.0
SAC42	RD 999	0.0	0.0	0.0	0.0	0.0
SAC43	Clarksburg	0.0	0.0	0.0	0.0	0.0
SAC44	Stone Lake	0.2	0.8	0.0	0.1	0.0
SAC45	Hood	0.2	0.0	0.0	0.0	0.0
SAC46	Merritt Island	0.0	0.0	0.0	0.0	0.0
SAC47	RD 551	0.0	0.0	0.0	0.0	0.0
SAC48	Courtland	0.0	0.0	0.0	0.0	0.0
SAC49	Sutter Island	0.0	0.0	0.0	0.0	0.0
SAC50	Grand Island	0.1	0.0	0.1	0.0	0.1
SAC51	Locke	0.0	0.0	0.0	0.0	0.0
SAC52	Walnut Grove	0.0	0.0	0.0	0.0	0.0
SAC53	Tyler Island	0.0	0.0	0.0	0.0	0.0
SAC54	Andrus Island	0.0	0.0	0.0	0.0	0.0
SAC55	Ryer Island	0.0	0.0	0.0	0.0	0.0
SAC56	Prospect Island	0.0	0.0	0.0	0.0	0.0
SAC57	Twitchell Island	0.0	0.0	0.0	0.0	0.0
SAC58	Sherman Island	0.0	0.0	0.0	0.0	0.0
SAC59	Moore	0.0	0.0	0.0	0.0	0.0
SAC60	Cache Slough	0.0	0.0	0.0	0.0	0.0
SAC61	Hastings	0.0	0.0	0.0	0.0	0.0
SAC62	Lindsey Slough	0.0	0.0	0.0	0.0	0.0
SAC63	Sacramento South	32.2	34.8	18.1	12.3	15.6
TOTAL			**58.6**	**56.0**	**31.6**	**23.2**

Notes:

[1] Although individual impact area results are presented in this table for completeness, the most appropriate comparison of the life risk values is on an aggregate, systemwide basis, comparing the relative differences in the reductions achieved by the approaches. See Section 4.2.

Key:
CVFPP = Central Valley Flood Protection Plan
EFSC = Enhance Flood System Capacity Approach
PHRC = Protect High Risk Communities Approach
RD = Reclamation District
SPFC = Achieve SPFC Design Flow Capacity Approach
SSIA = State Systemwide Investment Approach

Table 4-2. 2012 CVFPP Life Risk Values for San Joaquin River Basin (SJ) Impact Areas

Impact Area	Description	No Project	SPFC	PHRC	EFSC	SSIA
SJ01	Fresno	0.0	0.0	0.0	0.0	0.0
SJ02	Fresno Slough East	0.0	0.0	0.0	0.0	0.0
SJ03	Fresno Slough West	0.0	0.0	0.0	0.0	0.0
SJ04	Mendota	0.0	0.0	0.0	0.0	0.0
SJ05	Chowchilla Bypass	0.0	0.0	0.0	0.0	0.0
SJ06	Lone Willow Slough	0.0	0.2	0.0	0.1	0.0
SJ07	Mendota North	0.0	0.0	0.0	0.0	0.0
SJ08	Firebaugh	0.0	0.0	0.0	0.0	0.0
SJ09	Salt Slough	3.0	2.4	3.0	1.40	2.9
SJ10	Dos Palos	0.0	0.0	0.0	0.0	0.0
SJ11	Fresno River	0.0	0.0	0.0	0.0	0.0
SJ12	Berenda Slough	0.0	0.0	0.0	0.0	0.0
SJ13	Ash Slough	0.0	0.0	0.0	0.0	0.0
SJ14	Sandy Mush	0.0	0.0	0.0	0.0	0.0
SJ15	Turner Island	0.0	0.0	0.0	0.0	0.0
SJ16	Bear Creek	0.0	0.0	0.0	0.0	0.0
SJ17	Deep Slough	0.0	0.0	0.0	0.0	0.0
SJ18	West Bear Creek	0.0	0.0	0.0	0.0	0.0
SJ19	Fremont Ford	0.0	0.0	0.0	0.0	0.0
SJ20	Merced River	0.0	0.0	0.0	0.0	0.0
SJ21	Merced River North	0.0	0.0	0.0	0.0	0.0
SJ22	Orestimba	0.0	0.0	0.0	0.0	0.0
SJ23	Tuolumne South	0.0	0.1	0.1	0.0	0.1
SJ24	Tuolumne River	0.3	0.3	0.2	0.0	0.2
SJ25	Modesto	0.2	0.2	0.2	0.1	0.2
SJ26	Three Amigos	0.0	0.0	0.0	0.0	0.0
SJ27	Stanislaus South	0.0	0.0	0.0	0.0	0.0
SJ28	Stanislaus North	0.0	0.0	0.0	0.0	0.0
SJ29	Banta Carbona	0.1	0.2	0.1	0.1	0.1
SJ30	Paradise Cut	0.0	0.0	0.0	0.0	0.0
SJ31	Stewart Tract	0.0	0.0	0.0	0.0	0.0
SJ32	East Lathrop	0.0	0.0	0.0	0.0	0.0
SJ33	Lathrop/ Sharpe	0.3	0.2	0.1	0.1	0.1
SJ34	French Camp	0.0	0.3	0.0	0.0	0.0
SJ35	Moss Tract	0.0	0.0	0.0	0.0	0.0
SJ36	Roberts Island	0.0	0.0	0.0	0.0	0.0

Table 4-2. 2012 CVFPP Life Risk Values for San Joaquin River Basin Impact Areas (contd.)

Impact Area	Description	No Project	SPFC	PHRC	EFSC	SSI
SJ37	Rough and Ready Island	0.0	0.0	0.0	0.0	0.0
SJ38	Drexler Tract	0.0	0.0	0.0	0.0	0.0
SJ39	Union Island	0.0	0.0	0.0	0.0	0.0
SJ40	Union Island Toe	0.0	0.0	0.0	0.0	0.0
SJ41	Fabian Tract	0.0	0.0	0.0	0.0	0.0
SJ42	RD 1007	0.0	0.0	0.0	0.0	0.0
SJ43	Grayson	0.0	0.0	0.0	0.0	0.0
TOTAL			**4.1**	**4.0**	**3.9**	**2.0**

Notes:
[1] Although individual impact area results are presented in this table for completeness, the most appropriate comparison of the life risk values is on an aggregate, systemwide basis, comparing the relative differences in the reductions achieved by the approaches. See Section 4.2.

Key:
CVFPP = Central Valley Flood Protection Plan
EFSC = Enhance Flood System Capacity Approach
PHRC = Protect High Risk Communities Approach
RD = Reclamation District
SPFC = Achieve SPFC Design Flow Capacity Approach
SSIA = State Systemwide Investment Approach

Table 4-3. 2012 CVFPP Life Risk Values for Stockton Area Impact Areas

Impact Area	Description	No Project	SPFC	PHRC	EFSC	SSI
STK 01	Lower Roberts Island	0.1	0.0	0.0	0.0	0.0
STK 06	Stockton East	0.0	0.0	0.0	0.0	0.0
STK 07	Calaveras River	1.0	0.2	0.2	0.2	0.2
STK 08	Bear Creek South	0.0	0.0	0.0	0.0	0.0
STK 09	Bear Creek North	0.0	0.0	0.0	0.0	0.0
STK 10	Central Stockton	0.3	0.0	0.0	0.0	0.0
TOTAL			**1.4**	**0.2**	**0.2**	**0.2**

Notes:
[1] Although individual impact area results are presented in this table for completeness, the most appropriate reductions achieved by the approaches. See Section 4.2.

Key:
CVFPP = Central Valley Flood Protection Plan
EFSC = Enhance Flood System Capacity Approach
PHRC = Protect High Risk Communities Approach
SPFC = Achieve SPFC Design Flow Capacity Approach
SSIA = State Systemwide Investment Approach
STK = Stockton area impact area

4.2 Discussion of Results

These calculated life risk values were computed using HEC-FDA. Revised structure inventories (persons-per-structure relationships) and a water depth-percent mortality function were imported into the 2012 CVFPP HEC-FDA models, retaining the hydraulics and geotechnical inputs. HEC-FDA integrates the complex hydraulics, geotechnical, and consequence information, all of which affect the life risk values.

In addition to the traditional HEC-FDA inputs, the LRC Method also includes population information. Although population is not directly entered into HEC-FDA, for the LRC Method, it was *indirectly* entered with the residential persons-per-structure estimates that replaced the economic values (Tables 3-2, 3-3, and 3-4). These values were then reduced to account for evacuation as a result of existing flood warning system efficiencies and associated warning times (Tables 3-5, 3-6, and 3-7). Table 4-4 compares the 2000 population estimates and warning times for the Sacramento River basin impact areas with relatively high life risk values. As shown by this table, higher life risk values are consistent with higher population estimates. For example, the highest life risk value (32.2) was estimated for SAC63 (Sacramento South), which has the highest population of all 110 impact areas.

LRC Method results are also affected by warning times. As shown in Table 4-4, all impact areas with higher life risk values have mitigation times of 0 hours, except SAC36 (Natomas). With a 0-hour mitigation time, the number of persons per structure is not reduced to account for warning system efficiency. For example, the mitigation time for SAC36 was increased from 0 to 21 hours for this analysis. However, if the original Comprehensive Study mitigation time is used (0 hours), the resulting life risk value is 8.4 for SAC36.

Two other impact areas with higher life risk values are SAC40 (Sacramento North) and SAC63 (Sacramento South), both located along the American River in metropolitan Sacramento. Both of these impact areas show 0-hour mitigation times based on the Comprehensive Study estimates of forecast lead time and response time. Attachment A provides information on how the Comprehensive Study warning times were determined. For these two impact areas, a sensitivity analysis was conducted to determine the effect of a 2-hour mitigation time on the life risk values and relative ranking of the approaches. Not unexpectedly, the total life loss estimates were lower for these 2 impact areas, as shown in Table 4-5. The percent reductions among the approaches for all impact areas changed somewhat, as shown in Figure 4-4 (compared to Figure 3-1). However, more importantly, the relative ranking of the approaches, in terms of percentage reductions compared to the No Project condition, did not change significantly.

Table 4-4. Comparison of Population and Warning (Mitigation) Times for Impact Areas with High Life Risk Values

Impact Area	Description	2000 Population	Warning Time (hours)	No Project Life Risk Value
SAC63	Sacramento South	413,736	0	32.2
SAC40	Sacramento North	60,314	0	7.0
SAC25	Yuba City	58,020	0	8.2
SAC36	Natomas	41,141	21 (0)[1]	2.5 (8.4)[1]
SAC37	Rio Linda	26,173	0	1.7
SAC38	West Sacramento	25,605	0	2.4
SAC27	Linda-Olivehurst	25,516	0	1.2

Note:
[1] For comparison purposes, the original SAC36 mitigation time and resulting life risk value are shown in parentheses.

Table 4-5. Life Risk Values with 0 Hour and 2 Hour Mitigation Times for SAC 40 and SAC 63

Area	No Action	SPFC	PHRC	EFSC	SSIA
0 hour mitigation time					
SAC 40	7.0	6.0	3.2	3.0	3.2
SAC 63	32.2	34.8	18.1	12.3	15.5
2 hour mitigation time					
SAC 40	2.9	2.5	1.3	1.3	1.3
SAC 63	13.5	14.5	7.6	5.2	6.5

Key:
EFSC = Enhance Flood System Capacity Approach
PHRC = Protect High Risk Communities Approach
SPFC = Achieve SPFC Design Flow Capacity Approach
SSIA = State Systemwide Investment Approach

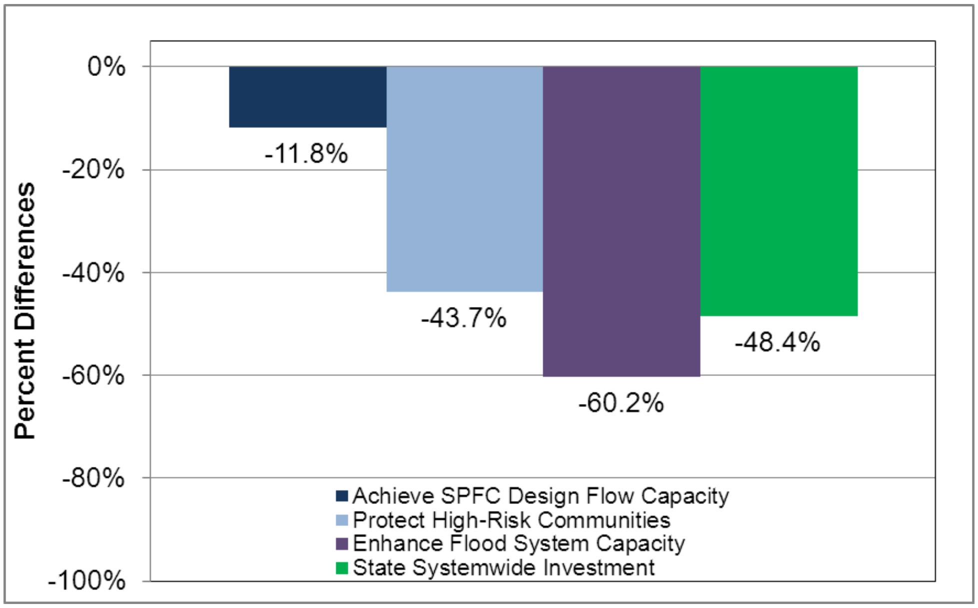


Figure 4-4. Total Life Risk Value Percent Reductions with 2 Hour Mitigation Times for SAC 40 and SAC 63

Although the Comprehensive Study mitigation times were developed almost 10 years ago, they are still believed to reflect current flood emergency forecast, decision making, and notification times for these two impact areas. Thus, the original Comprehensive Study 0-hour mitigation times have been retained for the No Project condition. However, it is recognized that improvements are, and will continue be, made in forecasting, emergency response, and notification in the Central Valley, which will further enhance the ability of the recommended State Systemwide Investment Approach to reduce flood life risk. This sensitivity analysis demonstrates how important these activities are for managing residual risk in the Central Valley.

The LRC Method results can be compared with results of the economic analysis. The same depths that were used to compute expected annual damages (EAD) were also used to compute life risk values. For example, the average depth of flooding for SAC63 for the p=0.002 (500-year) flood event is 6.71 feet which affects both the EAD and life risk values. Table 4-6 indicates that the higher life risk values are consistent with higher EAD estimates described in Attachment 8F: Flood Damage Analysis.

Finally, care should be used when interpreting the computed life risk values reported in Tables 4-1, 4-2, and 4-3 for individual impact areas. Because (1) uncertainties for the life risk consequence inputs were not defined (e.g., persons-per-structure relationships), and (2) because of the inherent precision of the calculations in HEC-FDA, the life risk values may not be significantly different than 0, especially the smaller values (e.g., 0.1).

In addition, caution must be used when comparing the life risk values with the expected annual damage (EAD) estimates presented in *Attachment 8F (Flood Damage Analysis)*. Although both estimates are sensitive to flood depths within the impact areas (one of the key HEC-FDA inputs), the EAD estimates are more sensitive to changes in shallower depths than the life risk values. This is because the slopes of the depth-% damage and depth-% mortality functions are very different, as shown in Figure 4-5. The depth-% damage function (the solid green line) is much steeper than the depth-% mortality function (the solid red line). Therefore, relative changes in EAD values in the individual impact areas may not necessarily correspond to relative changes in the life risk values, attributable to the different approaches.

The most appropriate comparison of the life risk values is on an aggregate, basin-by-basin basis, comparing the relative differences in the reductions achieved by the approaches, as shown in Figure 2-1.

Table 4-6. Comparison of HEC-FDA Expected Annual Damage and Life Risk Values for Impact Areas with High Life Risk Values

Impact Area	Description	Average Depth for p=0.002 Event (feet)	No Project EAD ($1,000)	No Project Life Risk Value
SAC63	Sacramento South	6.71	107,120	32.2
SAC36	Natomas	11.46	54,181	2.5
SAC40	Sacramento North	8.26	27,636	7.0
SAC38	West Sacramento	7.20	8,528	2.4
SAC25	Yuba City	3.64	58,944	8.2
SAC37	Rio Linda	7.47	4,917	1.7
SAC27	Linda-Olivehurst	5.86	2,080	1.2

Key:
EAD = expected annual damages
HEC-FDA = Hydraulic Engineering Center Flood Damage Analysis
p=0,002 event = 500-year event

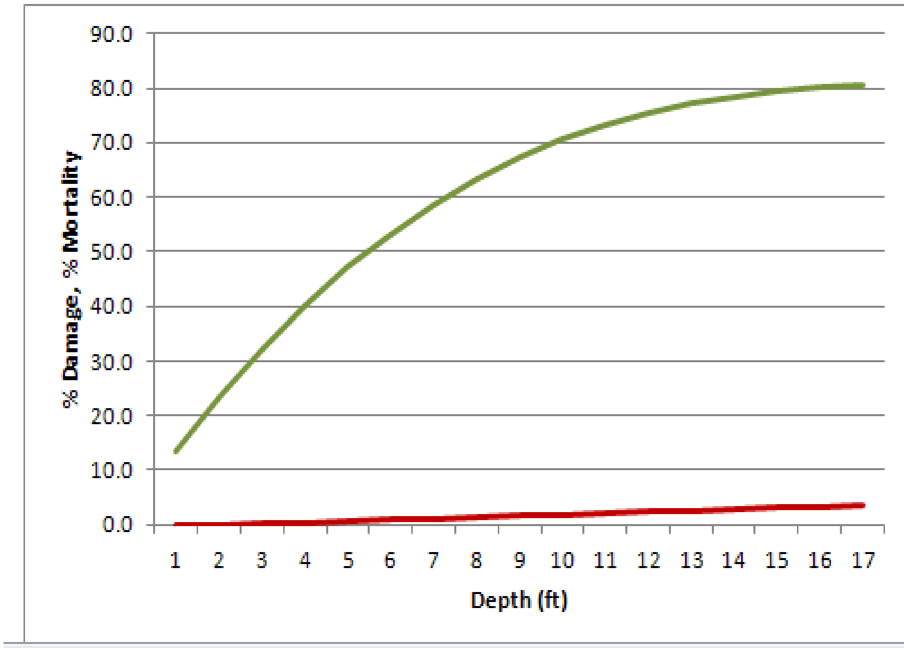


Figure 4-5. Comparison of Depth - % Damage and Depth – % Mortality Functions

4.3 Recommendations for Life Risk Analysis for 2017 CVFPP

For updates to the CVFPP, specialized off-the-shelf software applications, including HEC-FIA, HAZUS, and LIFESim, should be considered. If those applications are enhanced or otherwise modified to meet the needs for life risk analysis in the CVFPP, they may be used. However, such a wholesale change in analysis method is not required because the life risk analysis method used herein is acceptable and appropriate. It provides a systematic, unbiased, reproducible method for assessing risk to people protected by the project. Future refinements to the analysis might include (but are not limited to) the following:

- Future estimates of population exposed should be adjusted to account for time of day that flooding occurs. The analysis reported herein made no distinction between daytime and nighttime flooding. However, in some neighborhoods, such as downtown Sacramento, the population will be greater during business hours, while in other neighborhoods, such as the residential neighborhoods of Sacramento, population will be greater during the evening.

- Future estimates of population exposed should be adjusted to account for enhancements that come with improved emergency response. For example, DWR has projects underway to refine emergency response plans and to improve forecasting for communities subjected to flooding. These projects will increase the warning time, thus reducing the exposure of people to flooding. This improvement should be accounted for in future estimates of life risk.

- Future estimates of loading should use the best available models. For example, the flood depths used as the basis for computing consequence-probability functions for life risk analysis should be updated to use the results of the Central Valley Hydrology Study and the Central Valley Flood Evaluation and Delineation study.

- The latest census data should be used as each revision of the CVFPP is undertaken, thus accounting for increases, decreases, and shifts in population.

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6.0 Acronyms and Abbreviations

Board	Central Valley Flood Protection Board
Delta	Sacramento-San Joaquin Delta
Comprehensive Study	Sacramento and San Joaquin River Basins Comprehensive Study
CVFPP	Central Valley Flood Protection Plan
DWR	California Department of Water Resources
DEM	Digital Elevation Model
EAD	expected annual damage
FEMA	Federal Emergency Management Agency
GIS	geographic information system
Hazus-MH	Hazards U.S. Multi-Hazard
HEC	U.S. Army Corps of Engineers' Hydrologic Engineering Center
HEC-FDA	Hydrologic Engineering Center Flood Damage Analysis
HEC-FIA	Hydrologic Engineering Center Flood Impact Analysis
LRC	Life Risk Calculation
MFR	multi-family residential
MH	mobile home
MISC-RES	miscellaneous residential
SFR	single-family residential
SPFC	State Plan of Flood Control
State	State of California
USACE	U.S. Army Corps of Engineers

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CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

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Public Draft

2012 Central Valley Flood Protection Plan

Attachment 8G: Life Risk Analysis – Appendix A. Comprehensive Study Mitigation Times

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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Mitigation Times Summary

Comprehensive Study mitigation times were used to determine the flood warning efficiency factors used in the life risk calculation. This appendix describes how the Comprehensive Study mitigation times were determined. Further explanation is included in Appendix B (and Attachment 3) of the Enhanced Flood Response and Emergency Preparedness (EFREP) Initial Project Feasibility Study: Methods of Computing Damage Reduction (USACE 2003).

Flood Warning Timeline

Figure A-1 illustrates how time is spent responding to floods. The triangles represent milestones in the process, the last of which is exceedence of a threshold at which property is damaged, injuries occur, or lives are lost. If warning is available before that, mitigative actions can be taken. The goal of a flood warning system is to ensure that this is so. Mitigation time, shown in green in Figure A-1, is the time people have to take actions to reduce damage and avoid injuries and loss of life.

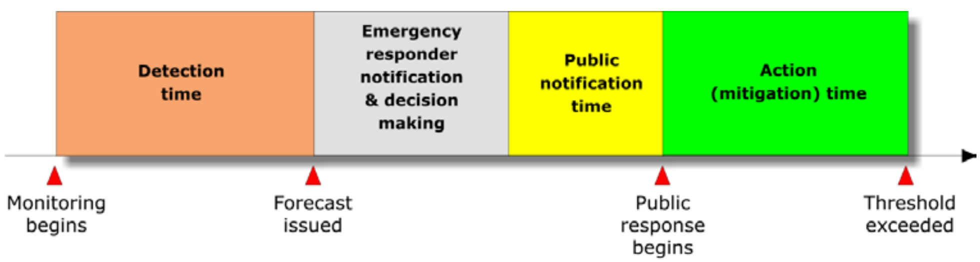

Figure A-1. How Time is Spent Responding to Floods

USACE (1996) provides guidance for estimating the warning time provided by a flood warning system. This guidance suggests that the maximum potential warning time is the time between the first detectable or predictable precipitation and the time at which the stage (water surface elevation) exceeds the threshold for damage or threat to life at a critical location (i.e., the time between *Monitoring begins* and *Threshold exceeded* in the timeline).

This maximum potential warning time varies from storm to storm and location to location. For example, if damageable property in a watershed is near the outlet, and if a short duration thunderstorm is centered near the outlet, the maximum potential warning time will be short. However, if the storm is centered at the far extent of the watershed, or if a forecast of the precipitation is available before it actually occurs (a quantitative precipitation forecast), the maximum potential warning time for this same location will be longer. Likewise, the watershed state plays a role in determining the maximum potential warning time: if watershed soils are saturated, the time between precipitation and runoff is shorter than if the watershed soils are dry.

But even if a storm is centered far from the outlet and soils are dry, the time available for mitigation may be short, because people are not able or willing to respond to a flood threat from the very onset or prediction of precipitation. For example, roads would not be closed, property moved, and evacuation commenced simply because a tipping bucket raingage tips in the upper reaches of a watershed. Thus, the actual warning time, the time truly available to take action to protect people and property, is less than the maximum potential warning time. The time between initiation of monitoring and exceedence of the threshold is spent completing other necessary tasks.

Some time is required to detect an event: to collect and transmit hydrometeorological data, to analyze these data, and to forecast the stage due to the precipitation. This block of time is labeled *Detection time* in the timeline in Figure A-1. After the forecast is developed, additional time is required for forecasters to provide the product to emergency responders at critical locations in the basins. These responders would take time to evaluate the product, to identify vulnerable people and property, and to make decisions about what to do. The block of time required for evaluation and notification by local responders is labeled *Emergency responder notification & decision making* time in the figure. The emergency responders take time to notify the public (labeled *Public notification time* in Figure A-1), who can then take action to protect themselves and their property. Finally, response begins. The time remaining for the response before the water-level threshold is exceeded is the *Action (warning or mitigation)* time. This is the time that yields the benefit in terms of property damage avoided and lives saved.

For example, suppose that the maximum potential warning time for a watershed averages 24 hours. That is, if emergency response began immediately on detection of rainfall in that watershed, the mitigation time available will be 24 hours. However, this kind of response is unlikely because the other activities described consume the time available. A few hours will be spent collecting and evaluating data, making decisions, notifying responders, and so on. Thus, the time actually available for mitigation will be less than 24 hours. If the system fails to detect that the rainfall rate is such that water levels are certain to rise to damaging levels, if the proper responders are not notified, or if an efficient response plan is lacking, the entire maximum potential warning time may be wasted. In that case, the mitigation time would be 0 hours, and the flood warning system would have no benefit.

However, if the flood warning system includes products and services that speed the evaluation and notification and improve the response, the flood warning system will increase the mitigation time. This will give responders and citizens more time to protect lives, property, lifelines, and the environment.

How Comprehensive Study Mitigation Times Were Determined

For the Comprehensive Study, DWR, National Weather Service forecasters, and Central Valley emergency responders were asked to provide estimates of the various times shown in Figure A-1 for conditions existing at the time of the study (2003) and forecast points throughout the Central Valley. These times were then correlated to the Comprehensive Study impact areas, which are nearly identical to the CVFPP impact areas.

The Comprehensive Study without-project condition mitigation times derived from this process are listed in Table A-1 for the Sacramento River Basin and Table A-2 for the San Joaquin River Basin.

Table A-1. Comprehensive Study Without-Project Condition Warning (Mitigation) Times for Sacramento River Basin

Impact Area	Description	Forecast lead time (hours)	Notification and decision making time (hours)	Warning time (hours)
SAC01	Woodson Bridge East	18	21	0
SAC02	Woodson Bridge West	18	12	6
SAC03	Hamilton City	18	21	0
SAC04	Capay	18	21	0
SAC05	Butte Basin	24	21	3
SAC06	Butte City	24	21	3
SAC07	Colusa Basin North	24	17	7
SAC08	Colusa	30	17	13
SAC09	Colusa Basin South	36	17	19
SAC10	Grimes	33	17	16
SAC11	RD 1500 West	39	35	4
SAC12	Sycamore Slough	42	21	21
SAC13	Knight's Landing	42	21	21
SAC14	Ridge Cut (North)	42	21	21
SAC15	Ridge Cut (South)	42	21	21
SAC16	RD 2035	42	21	21
SAC17	East of Davis	42	21	21
SAC18	Honcut	12	21	0
SAC19	Sutter Buttes North	12	21	0
SAC20	Gridley	12	21	0
SAC21	Sutter Buttes East	12	35	0
SAC22	Live Oak	12	35	0
SAC23	District 10	12	21	0
SAC24	Levee District #1	12	35	0
SAC25	Yuba City	12	17	0
SAC26	Marysville	12	21	0
SAC27	Linda-Olivehurst	12	21	0
SAC28	RD 784	15	21	0
SAC29	Best Slough	15	21	0

Table A-1. Comprehensive Study Without-Project Condition Warning (Mitigation) Times for Sacramento River Basin (contd.)

Impact Area	Description	Forecast Lead Time (hours)	Notification and Decision Making Time (hours)	Warning Time (hours)
SAC30	RD 1001	18	35	0
SAC31	Sutter Buttes South	33	35	0
SAC32	Rec Dist 70-1660	33	35	0
SAC33	Meridian	33	35	0
SAC34	RD 1500 West	39	35	4
SAC35	Elkhorn	42	21	21
SAC36	Natomas	8	21	0
SAC37	Rio Linda	8	17	0
SAC38	West Sacramento	8	21	0
SAC39	RD 900	45	21	24
SAC40	Sacramento	8	17	0
SAC41	RD 302	45	21	24
SAC42	RD 999	45	21	24
SAC43	Clarksburg	45	21	24
SAC44	Stone Lake	45	21	24
SAC45	Hood	45	21	24
SAC46	Merritt Island	45	21	24
SAC47	RD 551	45	21	24
SAC48	Courtland	45	21	24
SAC49	Sutter Island	48	21	27
SAC50	Grand Island	48	21	27
SAC51	Locke	48	21	27
SAC52	Walnut Grove	48	21	27
SAC53	Tyler Island	48	21	27
SAC54	Andrus Island	48	21	27
SAC55	Ryer Island	48	21	27
SAC56	Prospect Island	48	21	27
SAC57	Twitchell Island	48	21	27
SAC58	Sherman Island	48	21	27
SAC59	Moore	48	21	27
SAC60	Cache Slough	48	21	27
SAC61	Hastings	48	21	27
SAC62	Lindsey Slough	48	21	27

Source: USACE, 2003
Key:
RD = Reclamation District

Table A-2. Comprehensive Study Without-Project Condition Warning (Mitigation) Times for San Joaquin River Basin

Impact Area	Description	Forecast lead time (hrs)	Notification and decision making time (hrs)	Warning time (hrs)
SJ01	Fresno	12	27	0
SJ02	Fresno Slough East	12	27	0
SJ03	Fresno Slough West	12	27	0
SJ04	Mendota	12	27	0
SJ05	Chowchilla Bypass	12	27	0
SJ06	Lone Willow Slough	24	27	0
SJ07	Mendota North	24	27	0
SJ08	Firebaugh	24	27	0
SJ09	Salt Slough	30	15	15
SJ10	Dos Palos	24	15	9
SJ11	Fresno River	24	27	0
SJ12	Berenda Slough	24	27	0
SJ13	Ash Slough	24	27	0
SJ14	Sandy Mush	30	15	15
SJ15	Turner Island	30	15	15
SJ16	Bear Creek	48	15	33
SJ17	Deep Slough	39	15	24
SJ18	West Bear Creek	39	15	24
SJ19	Fremont Ford	48	15	33
SJ20	Merced River	48	15	33
SJ21	Merced River North	48	18	30
SJ22	Orestimba	48	18	30
SJ23	Tuolumne South	12	18	0
SJ24	Tuolumne River	12	18	0
SJ25	Modesto	12	18	0
SJ26	3 Amigos	42	18	24
SJ27	Stanislaus South	15	18	0
SJ28	Stanislaus North	15	12	3

Table A-2. Comprehensive Study Without-Project Condition Mitigation Times for San Joaquin River Basin (contd.)

Impact Area	Description	Forecast Lead Time (hours)	Notification and Decision Making Time (hours)	Warning Time (hours)
SJ29	Banta Carbona	48	12	36
SJ30	Paradise Cut	48	12	36
SJ31	Stewart Tract	48	12	36
SJ32	East Lathrop	48	12	36
SJ33	Lathrop/Sharpe	48	12	36
SJ34	French Camp	48	12	36
SJ35	Roberts Island	48	12	36
SJ36	Roberts Island	48	12	36
SJ37	Rough and Ready Island	48	12	36
SJ38	Drexler Tract	48	12	36
SJ39	Union Island	48	12	36
SJ41	Fabian Tract	48	12	36
SJ42	RD 1007	48	12	36

Source: USACE, 2003
Key:
RD = Reclamation District

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